Acta Mineralogica-Petrographica, Szeged, XXXVIII, Supplementum, 7–63, 1997

SECONDARY SULPHATE MINERALS FROM HUNGARY

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ABSTRACT

An overview is given in this paper by genetic types about the secondary sulphate minerals that occur in the territory of Hungary. At present we know about 60 secondary sulphate minerals from Hungary (Table 1). Numerous rarities occur among them, including bonattite, fornacite, koktaite and millosevichite.

The secondary sulphate minerals of the sulphide ore deposits and ore indications are quite variegated, indicating the variety of precursor sulphide minerals. Especially variegated sulphate parageneses occur in the ore deposits of Nagybörzsöny, Recsk and Rudabánya. In magmatic and sedimentary rocks, jarosite and gypsum commonly form the weathering of disseminated pyrite and/or marcasite grains. Bauxite deposits are particularly enriched in iron-sulphates. Secondary sulphates can be found in large amounts in all coal beds and especially on the burning dumps. The important occurrences are Tokod, Egercsehi and Miskolc-Lyukóbánya. A species-rich sulphate paragenesis is known from Lesenceistvánd, where it formed by the weathering of the marcasite that impregnates the sandstone.

1. INTRODUCTION

The secondary sulphate minerals appear in superficial and near-superficial parts of different geological formations. They usually occur in sulphide-bearing rocks, forming mainly by the weathering of sulphide minerals. The most important environments of formation of the secondary sulphate minerals in Hungary are:

1. zones of weathering of sulphide ore deposits,
2. zones of weathering of rocks that contain disseminated sulphides,
3. superficial and near-superficial layers of salting areas,
4. openings of mine workings,
5. material of the refuse dumps,
6. museum (collection) specimens.

The environments of the formation of secondary sulphates, listed under 1 to 3 are independent of human activity, but in the case under 4 to 6 the appearance of sulphate-bearing paragenesises are caused by anthropogeny influence. We did not include to the

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group of secondary sulphates samples that formed by hydrothermal (epithermal) processes (such as the most of barite occurrences and alunite and jarosite of hydroquartzites). Evaporites and sulphate-bearing mineral assemblages of caves are not listed either, because they consist first of all of primary segregations.

The secondary sulphates quite frequently have been mentioned in the Hungarian mineralogical literature. Most of such papers discuss minerals of abandoned mine workings, dumps of coal beds, bauxite beds and clays (KOCH, 1985).

Based on the large amount of sulphate mineral samples found by the staff of the Herman Ottó Museum (Miskolc) with the help of numerous collectors, tens of thousands of microscopic investigations and thousands of instrumental tests were done in the period between 1986 and 1996. The most important results of this work are summarized in this paper.

The instrumental tests usually have been done within 1–2 mounts after collecting: this is quite important, because among the sulphates, new mineral phases could form by water loss in the period of storage. Moreover, by our opinion, partial water loss could be also caused by X-ray radiation during the tests, resulting in difficulties in the interpretation. This could occur if a test was done on a specimen that was collected long ago, on a museum specimens, or on a sulphate mineral which formed on a museum specimen. With regard to the wealth of information, in this paper only short descriptions are given, except for those species that are described here. Hopefully, it will be possible to treat some parts in more detail in the future. Former results are completed with our new data and classified in genetic order in Table 1.

2. METHODS OF EXAMINATION

In the first stage, the separation of the different mineral phases was done using an optical microscope. Then energy-dispersive X-ray (EDX), scanning electron microscopy (SEM) and X-ray powder diffraction (XRD) analyses were performed. If necessary, other tests (thermal and IR analyses, wet chemical analyses) were applied. In this paper only those minerals are listed which were exactly identified by instrumental tests (as a minimum we applied EDX, SEM, XRD). The microprobe and SEM analyses were done at the Department of Metallography of the University of Miskolc. The thermal and IR-tests were made in the Hungarian Geological Institute, the X-ray powder diffraction analyses at the Department of Mineralogy of the Eötvös L. University, in the Hungarian Geological Institute, in the X-ray Diffraction Laboratory of the MOL Corp., and in the X-ray Diffraction Laboratory of the ALUTERV-FKI. Tests that were done in other institutions are always mentioned, together with the conditions of the particular analyses.

Test conditions:

University of Miskolc, Department of Metallography: SEM-EDX: AMRAY 1830i, EDAX 9900, 20 kV accelerating voltage, 10^{-10} A probe current, SiLi detector, W-cathode.

Eötvös L. University (ELTE), Department of Mineralogy: XRD: SIEMENS 500D, CuK_{α}-ray, graphite monochromator, 41 kV accelerating voltage, 20 mA tube current, the rotation rate of the goniometer was 1 or 2 degree/minute.

MOL Corp. Laboratory for Oil and Gas Industry, X-ray Diffraction Laboratory: XRD: PHILIPS PW 1820, CuK_{α}-ray, graphite monochromator, 40 kV accelerating voltage, 30 mA tube current, rotation step by step by 0.05 degree with count time of 1 sec.

Hungarian Geological Institute (MÁFI) X-ray Diffraction Laboratory: XRD: PHILIPS PW 1710, CuK_{α}-ray, graphite monochromator, 40 kV accelerating voltage, 30 mA tube current, rotation step by step by 0.04 degree with count time 1 sec.

MÁFI Thermoanalytical Laboratory: Derivatograph-C, heating rate 10°C/minute.

It is not possible to publish in this paper the documentations of each tests, but for the important specimens, the adequate test numbers and inventory numbers are mentioned. For the jarosite and copiapite groups additional analyses were necessary for further separation. XRD and EDX methods were used essentially for the investigation of the minerals of the quite frequently occurring jarosite group; using these two methods, the minerals of the jarosite group could be satisfactorily distinguished. When potassium and iron were detected together with sulphur in a jarosite-bearing phase, then we listed the mineral as jarosite. Numerous unidentified species of this group could still exist in Hungary because of the variable cation substitutions; in the future, it will be necessary to obtain more wet chemical analyses on these minerals.

3. SULPHIDE MINERALS AND THEIR OCCURRENCES

Because of the large number of occurrences, a genetic classification was applied for the description of the parageneses of secondary sulphate minerals. Within a genetic type, the minerals are listed by mountain ranges, or by occurrences, from west to east.

3.1. SULPHIDE ORE DEPOSITS AND ORE INDICATIONS

The ore deposits are ideal environments for the formation of secondary sulphate minerals. Three main environments of the oxidation of sulphide minerals are known: the oxidation belt near the surface, the walls of mine workings (especially the abandoned ones) and the dumps. Variegated sulphate mineral assemblages could be formed on different deposits, because of the variety of sulphide minerals (see Table 1).

Szabadbattyán

Sulphate minerals from this deposit are not mentioned in the monograph by KOCH (1985). Anglesite was described by KISS (1951) but was not found by us. Among the secondary sulphates, *gypsum* and *jarosite* occur rarely on the dump of the lead ore occurrence. Gypsum forms 2–3 mm long, acicular crystals, while jarosite occurs in light-yellow, dust-like tarnish. *Fornacite* was found once; this is the first finding of this mineral in Hungary, so we describe it in more detail.

Fornacite $CuPb_2(CrO_4AsO_4)(OH)$

This rare copper-lead-chromate-arsenate, which is included in the class of sulphates, was found on a museum specimen collected by PÁL KRIVÁN in the 1940's (HOM 21629). Bindheimite and malachite also appear in this specimen that consists mostly of cerussite. Fornacite occurs in the cracks of cerussite. It is darker than bindheimite, has a wine-yellow colour, glassy lustre, in places forming thin-tabular crystals of 10–40 μm, or 100–300 μm size (Fig. 1). The crystals rarely form crusts on the walls of the cracks. 21 reflections of fornacite were detected on the XRD patterns, which are in good agreement with the data in the JCPDS card 15-200 (Table 2). Cu, Pb, As and Cr were detected by the EDX analysis,

so the occurrence of fornacite can be considered as certain. The appearance of fornacite fits well into the suite of secondary sulphate minerals of the Szabadbattyán ore deposit, where Cu-, Pb- and As-bearing sulphides (e.g., galena, chalcopyrite, tetrahedrite) were found.

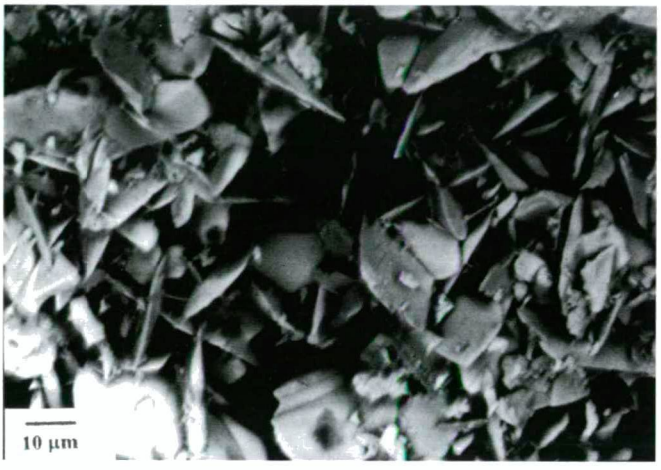

Fig. 1. Fornacite, tabular crystals, Szabadbattyán. Scanning electron micrograph.

Pátka

Jarosite occurs commonly and *gypsum* less commonly in the cracks and cavities of the siliceous-fluorite-bearing veins of the outcropped ore occurrences in the Kőrakás Hill and near the Szűzvár mill. Jarosite occurs in yellow, dust-like spots, and gypsum usually forms columnar crystals with sizes less than 1 mm. Anglesite – which was described by numerous authors – was not detected yet by our instrumental tests.

Sukoró

Jarosite occurs commonly in the formations of the ore indication on the Ördög Hill. The accompanying minerals are goethite, cerussite, sulphur and malachite.

Nadap

Yellow, dust-like dissemination of *jarosite* appears quite frequently, together with goethite and alunite in the widespread quartzite of the Meleg Hill. It occurs also commonly in the cracks and cavities of the material of the Nadap adit, where it was formed by the weathering of pyrite. By the XRD patterns, *plumbojarosite* occurs also in the cavities of the quartzite of the enargite-bearing indication, near Likas-kő. Plumbojarosite forms here yellow, dust-like tarnishes. The accompanying minerals are goethite, or more rarely bayldonite, forming yellowish-green tarnish, and a copper-arsenate mineral that occurs in light-blue crusts and has yet to be identified. These above listed arsenates appear directly in the surroundings of enargite grains, usually enclosing them, or in places enargite is fully replaced by these arsenates. 14 reflections of bayldonite were identified on XRD pattern G241, together with 2 reflections of plumbojarosite: the

100 at d=3.079 (3.066), and the 95 at d=5.96 (5.93). The values in the brackets are the corresponding values from JCPDS card 18-698 of plumbojarosite. Pb, Fe and S were detected by the EDX analysis of the jarosite-bearing phase, confirming the result of the X-ray diffraction.

Nagybörzsöny

A sulphate-rich paragenesis is known form the mine workings, which were opened by the surveying of the ore occurrence in the second part of this century. A review is provided by NAGY (1984). *Kröhnkite* was described by ERDÉLYI *et al.* (1957) with question mark and after that it was not possible to find another specimen of this mineral – we consider as uncertain information.

We found a significant amount of sulphates on the dumps near Rózsa Hill that were not yet described from this area. Recent sulphate bloomings have been formed in large amounts on the surface of the pyrite-marcasite-bearing rocks on the dumps of the Altáró and Lower Rózsa adit along with arsenates (SZAKÁLL *et al.*, 1994). The following sulphate minerals were identified by XRD, thermal, SEM and EDX tests: copiapite, gypsum, jarosite, melanterite, rozenite, römerite, siderotil, szomolnokite and voltaite. From these, jarosite and gypsum are widespread. Jarosite occurs commonly on the dump of the Upper Rózsa adit, in the material of the small outcrops on the peak of Rózsa Hill (SZAKÁLL *et al.*, 1995), and also on the dumps of the Lower and Upper Fagyosasszony adits. *Copiapite* appears in 2–3 mm-sized, yellow aggregates; *melanterite* forms greenish incrustations; *rozenite* occurs in 1–2 mm-sized, white, curved, fibrous aggregations; *szomolnokite*, together with rozenite can be found in dust-like aggregates, and *voltaite* appears in crusts of 0.1–0.2 mm-sized, poorly developed, black crystals (XRD C271, C272, L173). *Anglesite* appears rarely in the vein quartz of the Altáró, forming sub-millimetric, white, sawtooth-like crystal groups and white segregations on the quartz, together with arsenopyrite and galena (XRD C285). Among the sulphates that were identified from this deposit, *römerite* and *siderotil* were first found here in Hungary, so we introduce them in more detail.

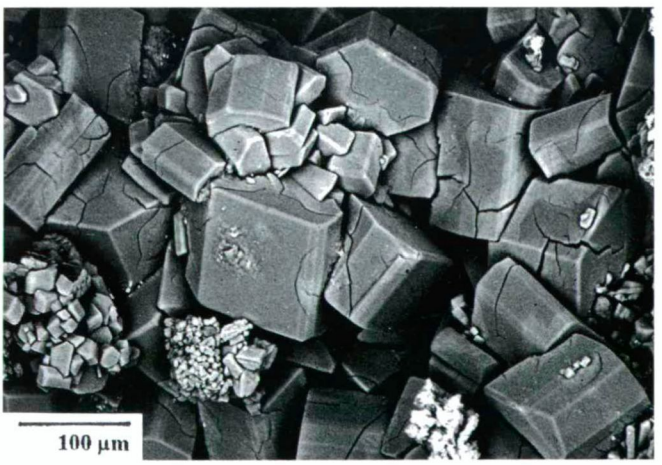

Fig. 2. Römerite crystals, Nagybörzsöny, drain adit. Scanning electron micrograph.

Römerite $Fe_3(SO_4)_4 . 14H_2O$

It was found in a sulphate-rich paragenesis, on the dump of Altáró. It forms 1–2 mm long, loose crusts and aggregates of sub-millimetric, light-pink crystals on the weathered surface of pyrite and marcasite (HOM 20820), and occurs in self-contained masses. By the SEM analyses, the stumpy crystals have 50–200 μm size and they are usually cracked (Fig. 2).

Wet chemical analysis of römerite from Nagybörzsöny give the following results:

	by specimen	by HÖLZEL (1982)	theoretically
Fe_2O_3*	27.3	29.3	29.8
H_2O	[29.5]	30.98	31.3
SO_3	40.3	38.4	39.8
Σ	97.1	98.68	100

*summarized FeO and Fe_2O_3.
[ ] – calculated from thermal analysis.
Analyzed by Mrs. I. SOHA (MÁFI).

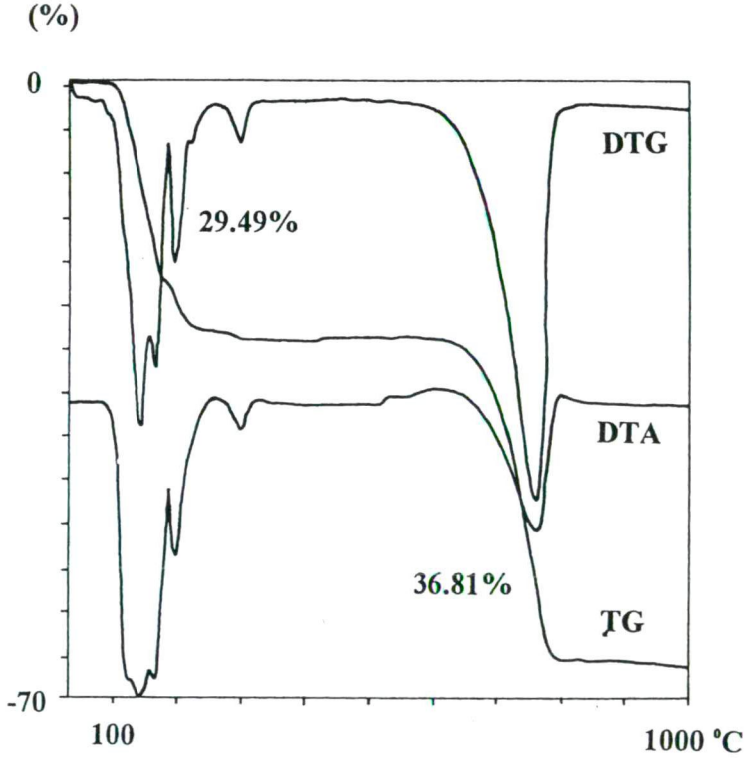

Fig. 3. Thermoanalytical curves of römerite from Nagybörzsöny.

The reactions that appear on the thermoanalytic curve (Fig. 3) are:

on the specimen		by TSVETKOV and VALYASCSHIKHINA
139–142 °C endothermic	16.79%	80–105 °C endothermic
165.3 °C endothermic	6.05%	105–135 °C endothermic
193–195 °C endothermic	5.4%	175–200 °C endothermic
296–298 °C endothermic	1.25%	220 °C endothermic
526.5–530.3 °C exothermic	?	410–620 °C exothermic (570 °C)
760–762.3 °C endothermic	36.81%	620–770 °C

The ignition losses by the TG curve are 67.16%.
The water-content and the ignition losses on the curve, published by CVETKOV and VALYASCSHIKHINA (1955) are 28.82% and 67.59%, respectively. This means that the curves of the test correlate well with the published data.

17 reflections of römerite were identified on the X-ray diffractogram (C273). The reflections with largest relative intensities are: the 100 – 4.78 (4.79), the 90 – 4.04 (4.03), the 50 – 5.08 (5.05) Å d values.

Fig. 4. Siderotil crystals, Nagybörzsöny, drain adit. Scanning electron micrograph.

Siderotil $(Fe,Cu)SO_4 . 5H_2O$

Together with other sulphates, it occurs on the weathered surface of the pyrite-marcasite-bearing rocks of the Altáró. The 2–5 mm sized siderotil crusts – formed by intergrowths of sub-millimetric, light-brown crystals – are accompanied by melanterite (HOM 23622). According to SEM images, these crusts are formed by 20–50 µm-sized, stumpy crystals, occasionally grouping into spherulitic aggregates (Fig. 4). The identification of this mineral was based on the XRD patterns No. C270 (Table 3), where 22 reflections appeared, in good agreement with the data of JCPDS card 22-357. The reflections of melanterite, gypsum, pyrite and quartz were detected together with siderotil on other XRD patterns (G270). An iron sulphate was detected by the thermal analysis,

obtained from a small amount (6.4 mg) of the sample, but the information is not enough for a detailed identification. The EDX test confirmed the presence of Fe, S and Cu.

Salgótarján

Gypsum and *jarosite* appear in minute amounts in the polymetallic ore indication of the andesite quarry of Karancs Hill, accompanying the altered sulphides.

Parádsasvár, Béke adit

Secondary sulphates are not mentioned in the literature (KOCH, 1985), but in the last years they have been intensively formed on the dump of the Béke adit. By the instrumental tests, the following minerals were identified: azurite, cerussite, devilline, gypsum, goethite, hematite, hemimorphite, hydrozincite, jarosite, cuprite, malachite and copper. Among the sulphates, *jarosite* forms dust-like tarnish, *gypsum* appears in mm-sized, acicular crystals, and *devilline* occurs in 0.2–0.6 mm sized, thin-tabular or lath-shaped, sky-blue crystals or in radial aggregates. This is the second appearance of devilline in the Mátra Mountains. It seems that the chalcopyrite- and calcite-rich material of the dumps of the Middle Mátra is a suitable environment for the formation of devilline. It commonly formed on the surface of the chalcopyrite crystals, accompanied by kaolinite. The five largest reflections appeared on the diffraction patterns, which agree well with the data on the JCPDS card 35-0561. The presence of Ca, Cu and S was identified by EDX, in agreement with the composition of devilline.

Gyöngyössolymos, prospect pit on Névtelen-bérc

The weathered dump of the prospect pit has been enriched by secondary sulphate minerals in the last years. According to KOCH (1985) and by our research, the following secondary minerals were detected: devilline, gibbsite, gypsum, goethite, greenockite, jarosite, kaolinite and malachite. *Gypsum* and *jarosite* appear commonly, whereas *devilline* occurs more rarely.

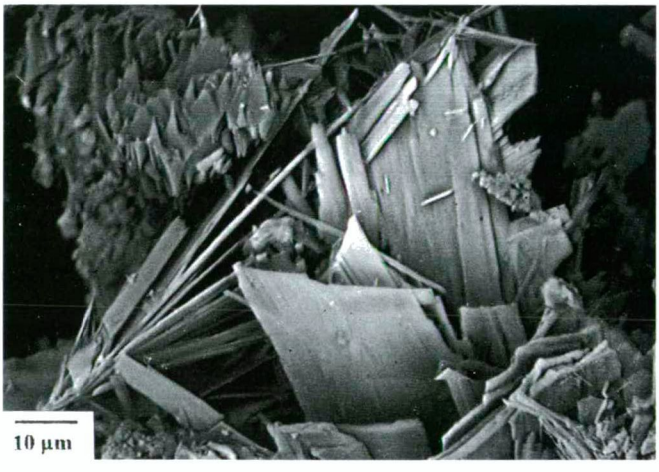

Fig. 5. Devilline, lath-like crystals, Gyöngyössolymos, Névtelen-bérc adit. Scanning electron micrograph.

Devilline $CaCu_4(SO_4)_2(OH)_6 \cdot 3\,H_2O$

The sky-blue, lamellar aggregations of devilline occur directly on chalcopyrite or in the cavities of vein quartz, forming 1–3 mm-sized radially-fibrous aggregates (HOM 22239). SEM images show that the aggregates consist of 20–80 μm long, lamellar and lath-shaped crystals (Fig. 5). Devilline usually appears with malachite and clay minerals. Three reflections of devilline, quartz, calcite and an unidentifiable clay mineral appear on the XRD patterns that where obtained from a small amount of the sample. The three reflections – which are the strongest reflections of devilline – do not overlap with other peaks and correspond to the three largest reflections published on JCPDS card 35-0561 of devilline:

Devilline from Névtelen-bérc:	10.23	5.12	3.40 (Å)
Devilline by JCPDS 35-0561:	10.22	5.10	3.39 (Å).

The diffractogram alone would not have been enough for the detection of devilline, because the three largest reflections of serpierite appear very close to the above listed values; however, EDX detected only Ca, Cu and S from these crystals. Since no Zn was detected, the presence of serpierite could be excluded.

Gyöngyössolymos, pits of Nyírjes

Only *jarosite* and *gypsum* were found from the sulphates on the weathered dumps. Goethite, hematite, malachite, copper, cuprite and clay minerals appeared as accompanying secondary minerals.

Recsk, Lahóca Hill

The earlier information about the sulphate-rich paragenesis of the old pits of the Lahóca Hill were summarized by KOCH (1985).

Secondary sulphates have been formed frequently by weathering on the dumps of Lahóca Hill. Jarosite and gypsum appear commonly. Chalcanthite also occurs, especially on the dump of the Rm-48 inclined adit. *Jarosite* forms yellow, dust-like tarnishes and *gypsum* appears in transparent, acicular aggregates. *Chalcanthite* forms ink-blue spots with glassy lustre in the cavities of the enargite-pyrite-bearing ore. *Szomolnokite* could be found frequently on the surface of the marcasite-bearing specimens that weathered during storage. It was formed probably as a pseudomorph after melanterite crystals, forming ocher-brown, massive, 1–3 mm-sized crystals with rough surfaces. 22 reflections of szomolnokite were identified on the X-ray diffractogram (G340). The three largest reflections with their relative intensities are: 100 – 3.42 (3.43), 40 – 3.08 (3.11), 34 – 2.51 (2.52) Å d values. (The data of the JCPDS card 21-925 are between brackets). Together with szomolnokite, the reflections of marcasite and quartz appear with small intensities. Rozenite and copiapite were detected in the close environment of the szomolnokite.

Coquimbite was detected by the X-ray powder patterns from a sulphate-bearing sample from the Lahóca Hill, Katalin level in the collection of the ELTE (K 100638) (oral communication of T. G. WEISZBURG).

Recsk, deep level

Numerous recent sulphate minerals were found in the adits of the Recsk deep level ore deposit (KISS & JÁNOSI, 1993). Unfortunately, a part of these were published without detailed information, so the appearance of these sulphates – by our opinion – is not fully

certain. The minerals which were detected by manifold instrumental tests (XRD, EDX, SEM) are the following ones: blödite, brochantite, chalcanthite, epsomite, thenardite and gypsum. From these recent segregations we also identified siderotil, sideronatrite and bonattite.

Siderotil was found by XRD (V153), occurring in yellowish-green crusts and in botryoidal aggregates. Nearly all 22 reflections of siderotil that are listed on JCPDS card 22-357 appeared on the diffractogram. Reflections with largest intensities were: 100 – 4.89 (4.89), 80 – 3.72 (3.73), 60 – 5.61 (5.57) Å d values (the data of the JCPDS card are listed in the brackets). The reflections of palygorskite were also found with small intensities. Fe- and S-contents were detected form these segregations by EDX.

Sideronatrite $Na_2Fe(SO_4)_2 \cdot 3H_2O$

This is the first occurrence of sideronatrite in Hungary. Its appearance is not surprising, because it is the iron-bearing analogue of the quite common magnesium-bearing blödite. Sideronatrite forms yellowish-brown crusts and spherulitic incrustations among the segregations of the level on –700 m (HOM 18722). The sub-millimetric spherules of the incrustations consist of radiating aggregates of 40–80 μm long, acicular crystals (Fig. 6.). According to XRD patterns, the accompanying minerals are halite and blödite. 18 reflections of sideronatrite were detected on the X-ray powder diffractogram (V154) (Fig. 7.). The largest reflections appeared at: 100 – 10.3 (10.2), 80 – 3.06 (3.01), the two 60 – 3.41 (3.38) and 2.72 (2.68) Å d values (data of the JCPDS card 17-158 are listed in brackets). Na, Fe, S and a small amount of Mg were detected by EDX.

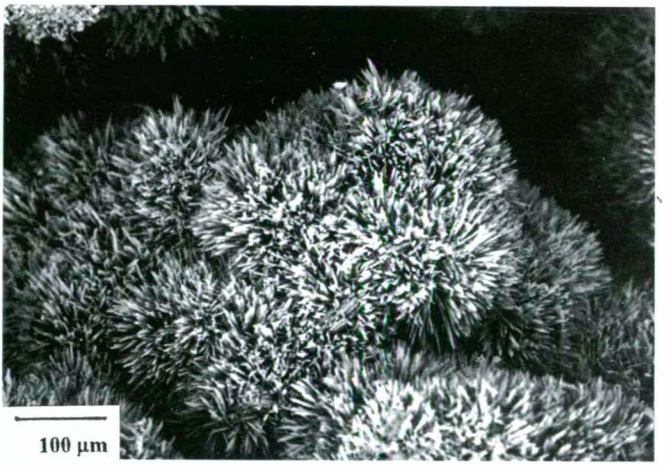

Fig. 6. Sideronatrite sprays, Recsk, –700 m level. Scanning electron micrograph.

Bonattite $CuSO_4 \cdot 3H_2O$

The quite rare *bonattite* is known from Hungary only from this deposit. It occurs in bluish-green incrustations, together with the dominant dypingite and with eriochalcite. We detected it by XRD, EDX and SEM tests. The 50–100 μm-sized spherules consist of radiating aggregations of lath-shaped crystals (Fig. 8.). 19 reflections of bonattite

appeared on the X-ray powder patterns (G350). The largest reflections, which appear without overlapping are at: 100 – 4.39 (4.41), 70 – 5.09 (5.10), 60 – 3.64 (3.64) Å d values (the data of the 22-249 JCPDS card is listed in the brackets). Cu and S were detected by EDX.

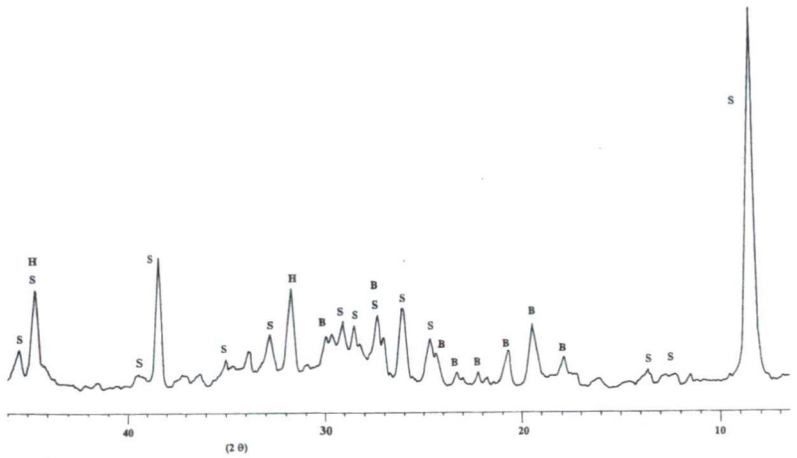

Fig. 7. X-ray powder diffractogram of sideronatrite, blödite and halite, Recsk, –700 m level. MOL Ltd., Budapest

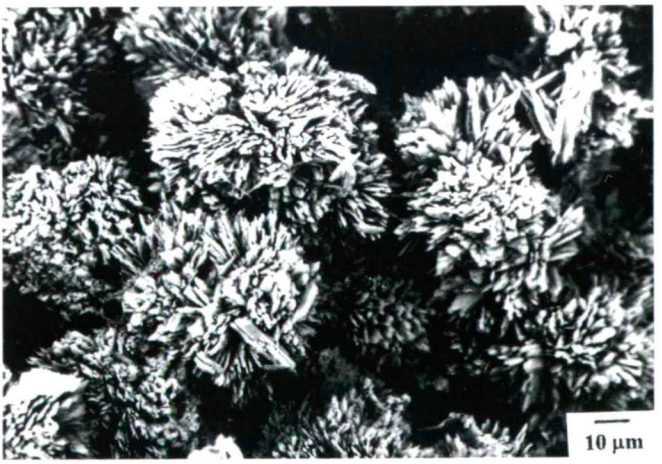

Fig. 8. Bonattite, globular aggregates. Recsk, –700 m level. Scanning electron micrograph.

Parád-Parádfürdő, Egyesség adit

Significant amount of ore-bearing specimens occur in the large depositing tanks that were used for alum production and are in front of the adit. Because of the abundance of water, sulphate-bearing blooms appear quite frequently in this area two arsenate segregations were found, too, but they are still not accurately identified). Coquimbite, gypsum, halotrichite and jarosite were detected from the sulphates by the instrumental tests (XRD V60, V87-88, C223). *Halotrichite* forms white, fibrous aggregates, *gypsum* occurs in colourless, acicular crystals and *jarosite* in yellow, dust-like tarnish.

Coquimbite $Fe_2(SO_4)_3 . 9H_2O$

Coquimbite in Hungary was first found here, as brownish-yellow, yellow crusts and aggregates, together with halotrichite. 25 reflections of coquimbite were detected on the X-ray powder patterns (Fig. 9.). The largest ones were at: 100 – 8.33 (8.26), 75 – 2.76 (2.75), 65 – 5.49 (5.45) Å d values (the data of the JCPDS card 6-0040 are listed in brackets). The reflections of the quartz, kaolinite and a not identified phase appear, too on the diffractogram. Fe and S were detected by EDX.

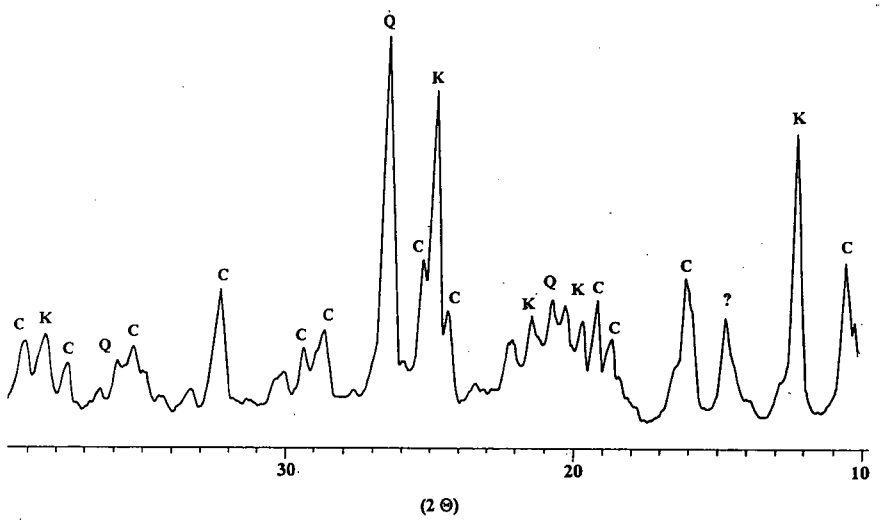

Fig. 9. X-ray powder diffractogram of coquimbite, kaolinite and quartz, Parád-Parádfürdő, Egyesség adit. Dept. of Mineralogy, ELTE, Budapest

Gyöngyösoroszi

The secondary sulphates of the Gyöngyösoroszi ore deposit were summarized by NAGY (1986). Based on XRD and EDX tests we complete this list with *thenardite* and *anglesite.*

Thenardite was found on the walls of mine workings, on the –100 m level of the Aranybánya adit, forming white, flour-like bloomings (HOM 19869). *Aglesite* was found in sub-millimetric, white spots or flour-like tarnish on the surface of galena crystals (XRD

C283). A characteristic secondary sulphate paragenesis has been formed by the weathering of sulphides in quartz veins, disseminated ore minerals, outcropping near the Upper Károly adit. It contains covellite, sulphur, malachite, gypsum, goethite, jarosite, hematite and anglesite. *Anglesite* – formed by the weathering of galena – occurs in crusts of sub-millimetric crystals on quartz.

Rudabánya

This large open pit is an ideal environment for the deposit of the secondary sulphates considering that the sulphide-bearing formations have been recovered on a large area. In addition to the information provided by KOCH (1985) and NAGY (1982), we detected the following sulphates that were unknown so far from this area: antlerite, botryogen, brochantite, copiapite, devilline, fibroferrite, jarosite, linarite, magnesiocopiapite, plumbojarosite, posnjakite, rozenite, serpierite, slavikite, starkeyite, siderotil and szomolnokite.

Brochantite (by XRD and EDX tests) appears in the cavities of the limonite ore of the Adolf mine, forming emerald-green, radiating spherules, intergrown with malachite, or forming self-contained, 50–200 μm-sized, thin-prismatic crystals in the cracks of the smithsonite, and also forming crusts. Parallel intergrown crystals occur quite commonly.

Jarosite is a widespread mineral in the outcrops, but usually occurs in small amounts only. It was found as a characteristic member of the sulphate paragenesis of the overlying lignitic seams, where the yellow, dust-like aggregations of this mineral appear together with melanterite, gypsum, rozenite and szomolnokite. This sulphate-bearing assemblage formed by the weathering of marcasite-pyrite concretions. In some outcrops of the Adolf mine, the clay, which is disseminated with pyrite, has a bright-yellow colour because of its fine dispersed jarosite content.

Siderotil

It was detected by XRD and EDX (G347) from the recent segregations of the Vilmos mine, where it occurs together with copiapite, forming brownish-yellow crusts.

Copiapite

It is a quite common sulphate, detected by us in the outcrops of all mines. Usually it forms 1–3 cm thick, pale-yellow, lemon-yellow, rarely orange crusts. On SEM images, the surfaces of these segregations consist of poorly developed and lamellar aggregates. By XRD, EDX and wet chemical tests, this mineral occurs here with variable compositions. Aluminocopiapite and gypsum were detected together with hexahydrite from the G232 specimen. The presence of these minerals was confirmed by thermal analyses. Aluminocopiapite is the main mineral of the G231 specimen with accompanying fibroferrite and gypsum. The G146 specimen consists of magnesiocopiapite, szomolnokite and rozenite in nearly equal proportions. Considering the positions of the thermal reactions and the proportions of the TG steps, the composition could also corresponds to magnesiocopiapite, but the steps of the water losses are different from the published reactions. By the X-ray patterns, the G145 specimen (Vilmos mine) consists of magnesiocopiapite (33 reflections), rozenite (20 reflections) and gypsum (8 reflections). The result of the XRD test was confirmed by thermoanalytic data, that showed ignition losses of 66.24%, measured up to 1001 °C.

The following thermal reactions appear on the curve of a sample that weighed 93.9 mg:

°C	weight changes (%)	reaction	
133–136	–11.88	loss of molecular water	
193	–13.55	loss of molecular water	
316–323	–0.87	loss of molecular water,	total water-content: 29.1%
356–362	–2.65	loss of molecular water	
431–483	+0.46	oxidation	
533–535	–0.15	dehydroxylation	
775.6	–29.32	decomposition of Fe-sulphate	
865–877	–2.04	decomposition of Al-sulphate,	total SO_3- content: >36.6%
>1000	–>5.23	decomposition of Mg-sulphate.	

The proportions of the reactions refer most likely to magnesiocopiapite with a small Al-content, but the steps of the reactions do not fully correspond to the published data. The presence of an iron sulphate mineral could be presumed by the amount of the weight loss near 360 °C.

By the wet chemical analyses (M. BRAUN, Kossuth L. University, Debrecen), the MgO-content of the copiapite minerals from Rudabánya varies between 3.58 and 5.79%, so this fact confirms also the presence of magnesiocopiapite among these sulphate-bearing segregations.

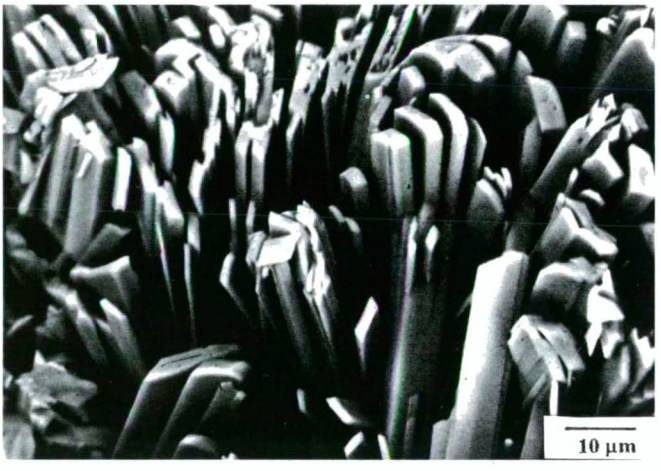

Fig. 10. Devilline, lath-like crystals, Rudabánya, Villanytető. Scanning electron micrograph.

Devilline

It was found in two outcrops from the open pit. In the outcrop below the „Villanytető" (Andrássy I mine), it was formed by weathering of copper-sulphides, occurring together with gypsum, jarosite, goethite, dolomite, claraite, barite and malachite in the fissures of the barite-bearing zone. Devilline segregations are usually associated with the 1–4 mm-sized tetrahedrite patches, forming crusts or appearing in their closest environment (HOM 24016). The sky-blue, lath-shaped, 0.2–0.5 mm long crystals are usually grouped into radiating or spherulitic aggregates, or they cover surfaces of a few cm^2 area (Fig. 10.). 21

reflections of devilline appeared on the XRD patterns (H2) (Fig. 11.). The largest ones occurred at: 100 – 10.20 (10.22), 95 – 5.10 (5.08), 80 – 3.19 (3.38) Å d values (the data of the JCPDS card are 22-231 listed in the brackets). 12 distinct reflections of the rare mineral claraite were detected on this diffractogram, from which only 3 are overlapped. Claraite was detected by EDX and SEM; the greenish-blue, 100–200 μm long crystals of this mineral are lath-shaped and usually form spherulitic aggregates. Ca, Cu and S were detected by most of the EDX tests of the devilline crystals; small amounts of Zn appeared in some analyses. Devilline was rarely found in the cracks of the earthy smithsonite in parts of the Adolf mine that are rich in secondary sulphates. Devilline forms 0.2–0.4 mm-sized, lamellar aggregates, accompanied by aurichalcite and cerussite.

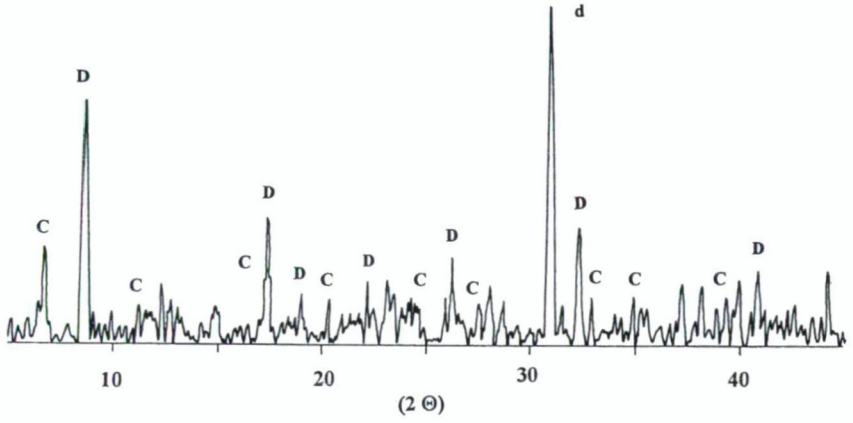

Fig. 11. X-ray powder diffractogram of devilline, claraite and dolomite, Rudabánya, Villanytető. Dept. of Mineralogy, Steiermärkisches Landesmuseum Joanneum, Graz.

Plumbojarosite

It occurs in the cavities of the siliceous limonite of the Adolf mine, forming 0.2–0.6 mm-sized, light-brown or yellowish tabular crystals with development of the basal and the rhombohedral faces or appearing in incrustations (HOM 22113). The presence of this mineral was confirmed by XRD (G82) and EDX (Pb-, Fe-, S-content) tests. The largest reflections occur on the X-ray patterns at: 100 – 3.068 (3.066), 95 – 5.93 (5.93), 35 – 3.11 (3.11) Å d values (the data of the JCPDS card 18-698 are listed in the brackets). The common accompanying minerals are beudantite, cerussite and malachite.

Rozenite and *szomolnokite* were found by us in the northern part of the Andrássy II. mine, in the lignite seams of the covering clay layers (G234). Pyrite and marcasite appeared frequently both in the lignite and in the clay, forming nodules of a few cm size. Rozenite and szomolnokite formed by the weathering of these nodules, close to the surface. Rozenite and szomolnokite were detected from the yellow, crust-like blooms of the Vilmos mine, too (G146).

Starkeyite, hexahydrite, epsomite

They are probably the most widespread minerals on the surface of the extended outcrops of the Vilmos, Andrássy I., and Andrássy II. mines. They form white or colourless, vitreous crusts, or white, flour-like disseminations. After desiccation, they turn into a white dust. They occur especially frequently in the Vilmos mine, on the walls of the adit below the so-called „Majomtelep", forming 2–5 cm thick crusts. Hexahydrite (62 reflections), starkeyite (43 reflections) and gypsum (19 reflections) were detected on the G114 X-ray patterns. Epsomite (27 reflections), hexahydrite (42 reflections) and gypsum (11 reflections) appeared on the G229 diffractogram with the dominance of epsomite. Similar phases were found in other specimens from this area (G230, G348), but in these the dominant mineral was hexahydrite. In the G232 specimen, the dominant hexahydrite is accompanied by gypsum and copiapite.

In the following part, antlerite, botryogen, fibroferrite, linarite, posnjakite, slavíkite and serpierite will be described in detail, because these were first in Hungary in Rudabánya.

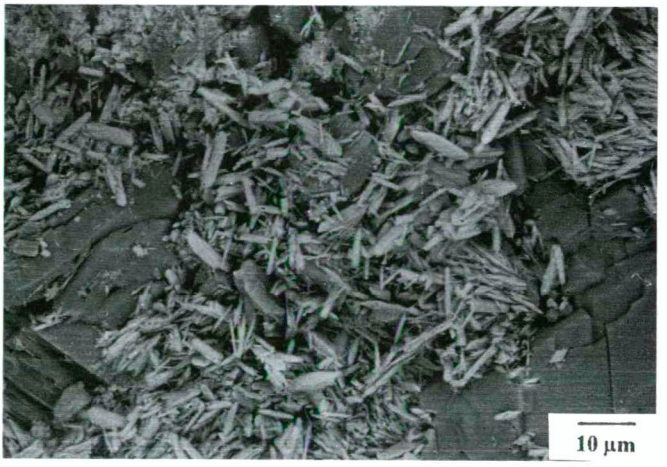

Fig. 12. Antlerite needles, Rudabánya. Scanning electron micrograph.

Antlerite $Cu_3SO_4(OH)_4$

It was found in numerous places of the oxidation zone of the Rudabánya iron ore deposit. By our investigations, it is the most frequent copper sulphate. It occurs together with malachite in the cracks of the brown iron ore, in the outcrops below the „Villanytető", forming light-green, dust-like dissemination. We have two series of the collected specimens (HOM 19621, HOM 20152) which contain antlerite, but their locality cannot be identified. In one of these, antlerite forms light-green, loose, dust-like, sometimes spherulitic aggregations on the walls of the cracks in the brown iron ore. In SEM images, these aggregations consist of acicular, 5–25 μm long crystals (Fig. 12). Malachite, barite and goethite appear in the closest environment of these aggregations. In the other occurrence in lignite the light-green, dust-like aggregates of this mineral are accompanied by fibrous segregations of chalcanthite. All these observations point to the secondary genesis of antlerite in the zone of oxidation. Usually it formed together with malachite, probably by the weathering of chalcopyrite. On the other hand, sometimes it has another

genesis, as we found a 2 cm thick vein-filling, which consist of small covellite lamellae covered by a thin crust of antlerite (G297).

The result of the wet chemical analysis (in weight%) is the following:

	from Rudabánya	by HÖLZEL (1992)
CuO	64.4	67.08
H_2O	[8.8]	10.22
SO_3	26.8	22.40
Σ	100	99.70

Analyst: Mrs. I. SOHA (MÁFI) (the H_2O was calculated by the completing to 100%).

13 reflections of the antlerite appear on the XRD patterns, which correlate well with the data of the JCPDS card 7-407 (Table 4).

Fibroferrite

It was found among the recent segregations in the Vilmos mine, from the lower part of the so-called „Vilmos-Nagyfal" (HOM 23584). It occurs in yellowish, fine-grained crusts, together with dominant aluminocopiapite. The detected reflections mostly relate to the JCPDS card of aluminocopiapite. Aluminocopiapite has 31 reflections, fibroferrite 19 reflections and gypsum 12 reflections on the XRD diffractogram (G231). By the peak-widths, the specimen contains aluminocopiapite in 80% and fibroferrite in 10%. The largest reflections of the fibroferrite appear at: 100 – 11.7 (12.1), 80 – 2.97 (2.98), the three 60-s – 6.83 (6.96), 3.45 (3.43) and 2.77 (2.78) Å d values (Fig. 13.). From these, only the reflection by 3.43 Å is overlapped (the data of the JCPDS card 16-935 are listed in the brackets).

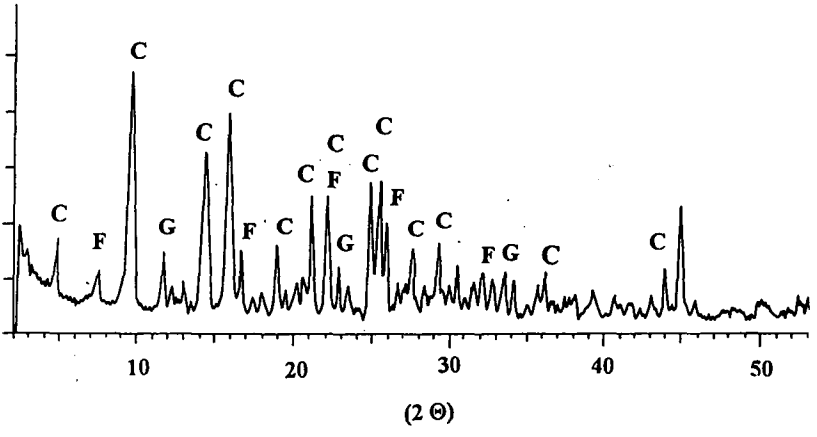

Fig. 13. X-ray powder diffractogram of fibroferrite, copiapite and gypsum, Rudabánya. MÁFI, Budapest

On the curve of the thermal analysis (Fig. 14.), the arrangement of the reactions and the proportions of the steps correspond to copiapite. The steps of the reactions are slightly different from the published data, indicating that this specimen first of all contains an OH-bearing, three valent iron sulphate mineral (fibroferrite by XRD).

Ignition losses measured up to 1000.3 °C were 62.19%.

The following thermal reactions appeared on the curve of a sample that weighed 102.4 mg:

°C	weight losses (%)	reaction	
133–136	12.35	loss of molecular water	
193–196	14.58	loss of molecular water	total water-content: 31.38%
366–381	2.1	loss of molecular water	
525–538	2.35	dehydroxylation	
752–753	25.44	decomposition of Al-Fe-sulphate	
994–995	>6.78	decomposition of Mg-sulphate, total SO_3-content: >32.22%	

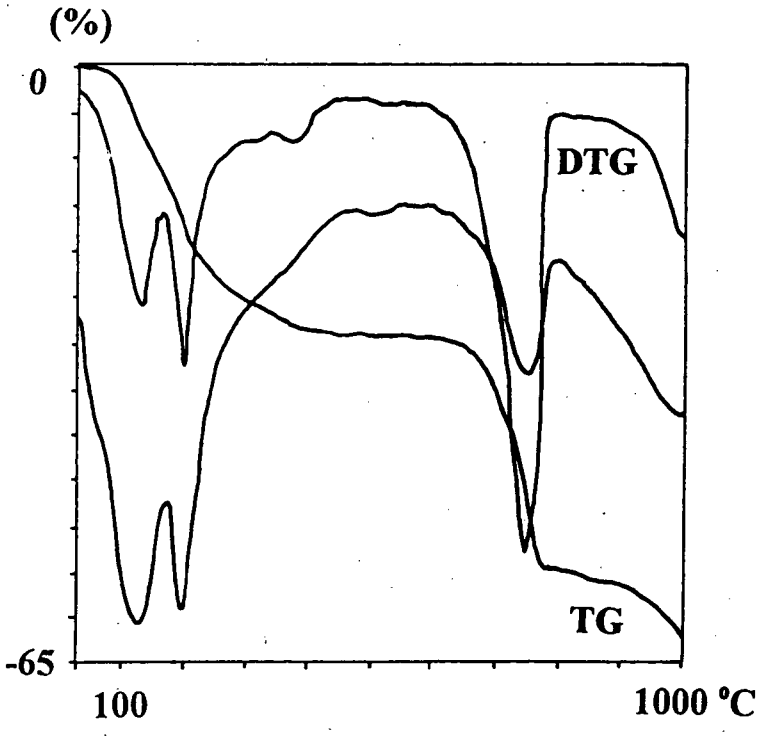

Fig. 14. Thermoanalytical curves of fibroferrite, copiapite and gypsum from Rudabánya.

A very small amount of alumina and a significant amount of magnesium was detected by the wet chemical analysis of the specimen. Magnesiocopiapite could be the other dominant sulphate mineral, which accompanies fibroferrite. The coexistence of these two

phases was confirmed by the crystal morphology, because on SEM images copiapite forms diverse, 5–15 μm-sized grains or lamellae, whereas fibroferrite appears in 50–200 μm-sized, fibrous aggregates (Fig. 15).

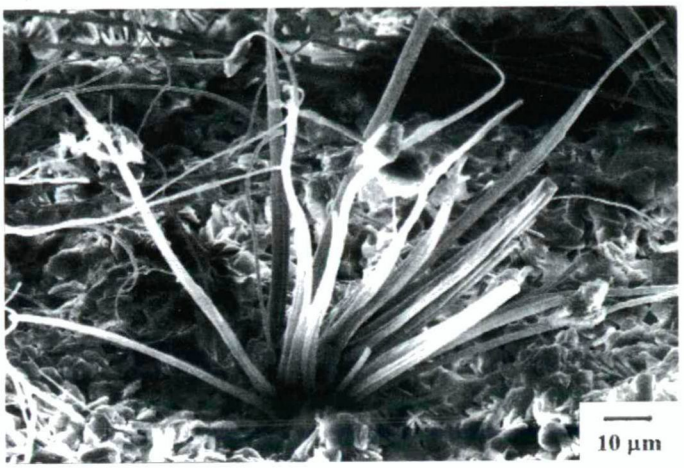

Fig. 15. Fibroferrite, needle-like crystals, Rudabánya, Vilmos mine. Scanning electron micrograph

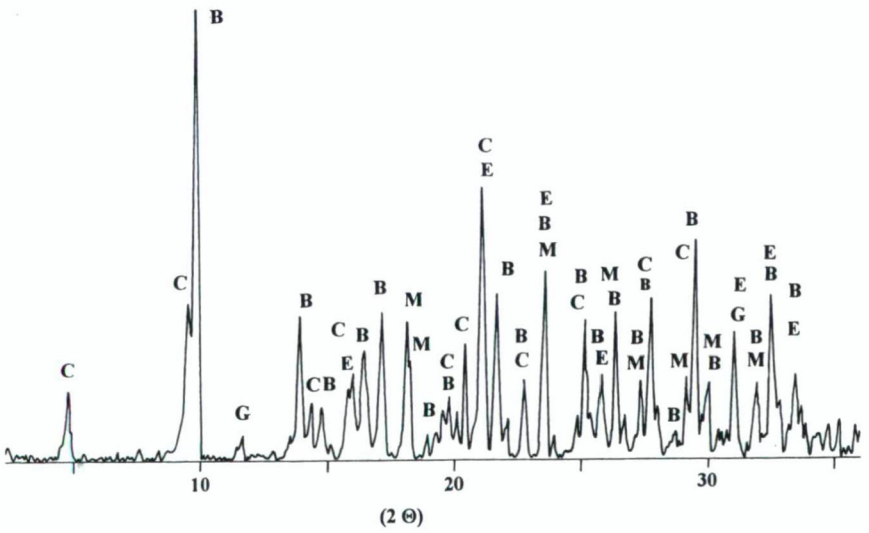

Fig. 16. X-ray powder diffractogram of botryogen, copiapite, epsomite, gypsum and melanterite, Rudabánya, Andrássy III mine. MÁFI, Budapest

Botryogen $MgFe(SO_4)_2(OH) \cdot 7H_2O$

It was found in the open pit of the Andrássy III mine. Yellow and orange spots of a few cm^2 size appeared on the wall of the outcrop, forming incrustations on the disseminated sulphides (HOM 23953). By the result of the XRD test of these orange segregations (H9), the dominant phase is botryogen, which is accompanied in decreasing order by epsomite, melanterite, gypsum and copiapite (by the XRD the most part of the yellow spots consist copiapite). 13 reflections of botryogen were detected on the X-ray patterns (Fig. 16). The diffractogram best corresponds to zincobotryogen:

Rudabánya		botryogen, 17-157		zincobotryogen, 34-186	
8.928	100	8.87	100	8.963	100
6.343	30	6.29	60	6.354	60
5.161	30	5.11	60	5.166	75
3.029	45	2.998	80	3.027	60

A 1.42 % zinc-content was detected by the chemical analysis of the specimen, indicating that the mineral could be identified as botryogen, even though this specimen contains five minerals. If the five minerals appeared in equal proportions, then the ZnO-content would be 0.8%. Therefore both by the chemical analysis and by the XRD test it is sure that the dominant mineral is botryogen. If it occurs in more than 35%, then the analysed phase is zincobotryogen; if it is less, then this is a zinc-bearing botryogen. While we cannot establish the proportions of the phases then it could be named as zinc-bearing botryogen. Further analyses would be necessary to answer this question. The results of the chemical analysis are the following:

ZnO	1.42
MnO	0.77
FeO	15.95
MgO	6.83
CuO	0.24
SO_3	33.67
PO_4	1.50
K_2O	0.17
SiO_2	0.13
H_2O	[35.60]
Σ	96.28

Analyst: Mrs. I. BALLÓK (MÁFI), Method: ICP, []: the H_2O-content was determined by thermoanalysis.

Mosaic pattern can be observed on SEM images, indicating the desiccation of the surface of the incrustations.

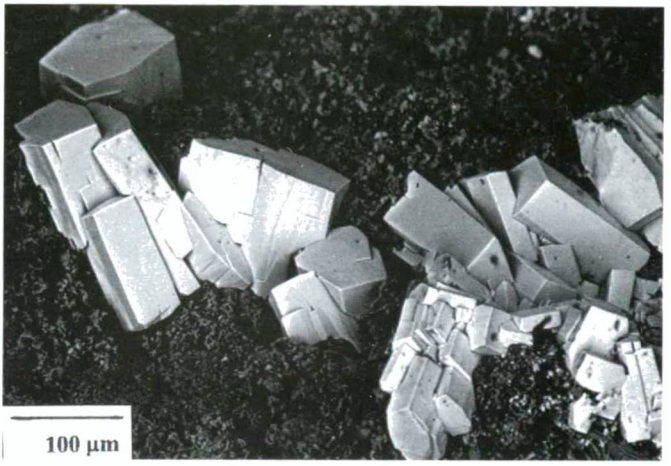

Fig. 17. Linarite crystals, Rudabánya, Adolf mine. Scanning electron micrograph.

Linarite $CuPbSO_4(OH)_2$

This is a member of the sulphate-rich secondary mineral paragenesis in the Adolf mine. It usually forms 1–2 mm thick, light-blue seams in the earthy masses of smithsonite (HOM 23315). 1–3 mm-sized aggregates of tabular or prismatic, sky-blue crystals, and radiated-bunched aggregations that occur in the cracks (Fig. 17). Oriented intergrowths of 3–6 crystals appears frequently. 16 reflections of linarite can be detected on the X-ray patterns, which correspond to the data of the JCPDS card 4-598 (Table 5). Pb, Cu and S were detected by EDX. In addition to smithsonite, the following minerals can be found in the closest environment: goethite, brochantite, malachite, aurichalcite, jarosite, cinnabar and cerussite.

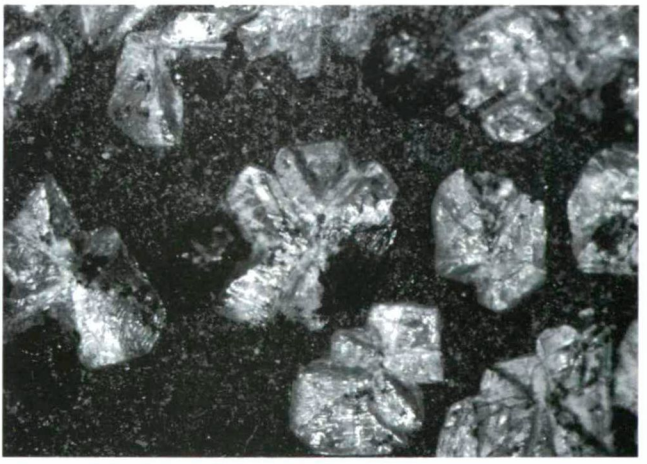

Fig. 18. Posnjakite, tabular crystals, Rudabánya. Width of the picture 0.9 cm.

Posnjakite $Cu_4SO_4(OH)_6 \cdot H_2O$

It is known only from a museum specimen (HOM 18599) that originated from a not exactly identified area of the open pit. Sky-blue, 1–2 mm pseudohexagonal, thin-tabular single or rarely grouped crystals of this mineral occur on the surface of the sample, which contains disseminated pyrite and marcasite (Fig. 18). The crystals are associated with sulphide-bearing patches, so they formed by the weathering of sulphides. The presence of posnjakite was confirmed not only by the morphology of the crystals, but also by X-ray patterns (Table 6) and EDX tests that showed copper and sulphur. Because of the overlapping peaks of posnjakite and other phases (pyrite, quartz, goethite), it could be identified only by the peaks: 100 at 6.95 (6.94) Å and the 10 at 3.45 (3.47) Å (the data of the JCPDS card 20-364 are listed in the brackets).

Slavíkite $NaMg_2Fe_5(SO_4)_7(OH)_6 \cdot 33H_2O$

In Hungary, first it was found in the open pit of the Andrássy III. mine (HOM 23773). It occurs rarely, forming yellowish-green, crust-like aggregates, which in fresh state are soft and after desiccation become hard. Three sulphate phases were detected by XRD obtained from these crusts (A72a). They include slavíkite, melanterite and a small amount of gypsum. 22 reflections of slavíkite appeared on the X-ray patterns. The largest, not overlapped ones were: the 100 at 8.99 (9.04) Å and the five 80-s at 11.6 (11.7), 5.81 (5.83), 5.40 (5.41), 4.19 (4.21) and 3.45 (3.47) Å d values (the data of the JCPDS card 20-679 are listed in the brackets). Slavíkite occurs in 0.1–0.5 mm-sized, hexagonal tabular crystals, on which the {0001} is well developed. On SEM images, the tabular crystals are rather cracked because of water losses (Fig. 19.). Fe, Mg and S and in traces Cu and Na were detected by EDX.

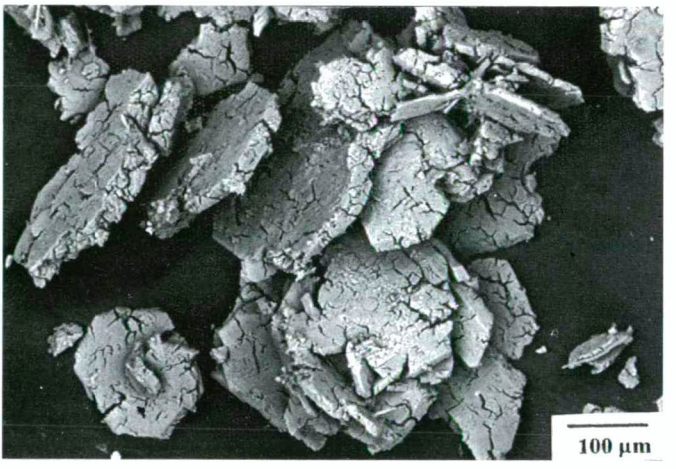

Fig. 19. Slavíkite, tabular crystals, Rudabánya, Andrássy III mine. Scanning electron micrograph.

Serpierite $Ca(Cu,Zn)_4(SO_4)_2(OH)_6 \cdot 3H_2O$

It was found in the cavities of a museum specimen (HOM 11413) that originated from an unknown point of the open pit. By the paragenesis, this specimen belongs to the zone of

oxidation. An interesting secondary mineral assemblage occurs on the black crusts of the cavities of the limonite ore that consists of tennantite (by XRD and EDX). Still not fully identified, blue and green, botryoidal incrustations and blue radially-fibrous aggregates have been formed by the weathering of tennantite (Fig. 20).

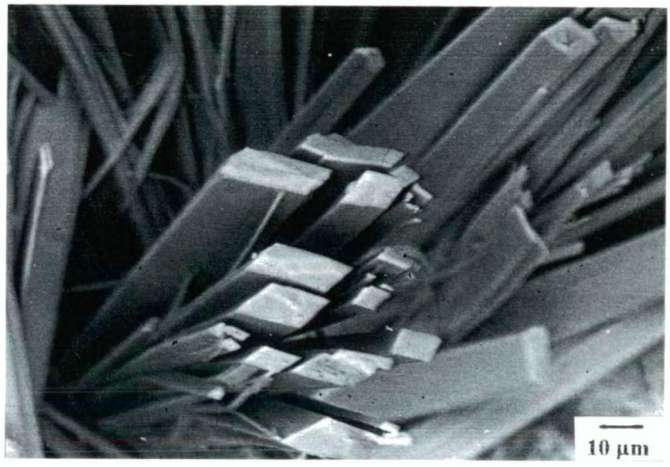

Fig. 20. Serpierite spray, Rudabánya. Scanning electron micrograph.

These 1–2 mm-sized, radiating aggregates of sky-blue, lath-shaped, columnar crystals consist of serpierite, according to XRD and EDX tests. 9 reflections of serpierite appear on the X-ray patterns; among these, the peak at 2.16 Å is the only one that is characteristic for serpierite but not for devilline, which has a similar diffractogram (Table 7). The EDX test detected sulphur and both copper and zinc. According to a semi-quantitative microprobe test the Cu:Zn ratio is 3:1, which compared with the published data (HÖLZEL, 1992) indicates a Zn-poor serpierite.

Martonyi

A small amount of secondary sulphates occurs in the material of the abandoned open pit. Compared to Rudabánya, this deposit is much poorer in sulphides. *Gypsum* forms 1–2 mm-sized, acicular aggregates and the *jarosite* appears in yellow, dust-like tarnish, or earthy masses. *Posnjakite* rarely found as skye-blue, fine-grained aggregates or minute (less than 1 mm) columnar crystals according to XRD (A. Roberts, Geol. Survey of Canada, oral communication) and EDX tests (HOM 24153).

Telkibánya

The sulphate minerals of the deposit were described by SZÉKY-FUX (1970) and SZAKÁLL *et al.* (1994).

3.2. SECONDARY SULPHATES IN MAGMATITES (IN THE ENVIRONMENT OF DISSEMINATED SULPHIDES)

Among the secondary sulphates – except for a few exceptions –, only gypsum and jarosite occur in magmatic rocks, but they are much more widespread that it was known before. According to our data, jarosite and gypsum appear in the surroundings of nearly all pyrite and/or marcasite disseminations, veins or crusts (see Table 1.). Both sulphates formed by the weathering of iron sulphides and potassium- or calcium-rich silicates. They appear nearly by the same origin in hydroquartzites formed by the postvolcanic activity of magmatites, first of all in the Mátra and Tokaj Mountains. *Gypsum* usually forms 1–3 mm long acicular crystals and aggregates, while *jarosite* appears in yellow, dust-like tarnishes the apparently as common occurrence of jarosite may be related to the fact that it usually forms together with goethite, or it turns into goethite by weathering.

The sulphate parageneses that are different form the above listed ones and were instrumentally tested, are the following:

– *Szomolnokite* was detected by XRD and EDX tests from weathering products of the quartz inclusions disseminated with pyrite, in the andesite quarry of Kisnána.

– *Jarosite, gypsum* and *halotrichite* and first of all goethite formed by weathering of the surface of the andesite disseminated with pyrite, in the abandoned andesite quarry near the Rudolf-tanya, Parádsasvár.

– During storage, *copiapite, rozenite* and *szomolnokite* formed by weathering of marcasite on the surface of the (usually dark-grey coloured) limnoquartzite specimens from Rátka (Hercegköves quarry), containing disseminated marcasite (XRD G54).

– Andesite of the quarry of Kopasz Hill, Tállya frequently contains disseminated pyrite along fissures. *Gypsum*, formed by weathering of pyrite was mentioned by TOKODY (1965). White, yellowish-white blooms of Mg-sulphates – *hexahydrite, pickeringite* and *epsomite* appear by weathering on the surface of pyrite-bearing andesite (XRD E16, G65).

3.3. SECONDARY SULPHATES IN SEDIMENTARY ROCKS (IN THE ENVIRONMENT OF DISSEMINATED SULPHIDES)

Gypsum and *jarosite* appear commonly in sedimentary rocks. They occur in any kinds of sedimentary rocks that contain disseminated pyrite and/or marcasite; their formation is similar to those ones, which have been formed in magmatic rocks.

3.3.1. SEDIMENTARY MANGANESE DEPOSITS

Úrkút, Eplény

Gypsum occurs commonly in the clay that covers the manganese ore bodies (KOCH, 1985). Rarely we found earthy, yellow tarnishes that consist of *jarosite* (HOM 22973).

3.3.2. SEDIMENTARY URANIUM DEPOSITS AND URANIUM INDICATIONS

Kővágószőlős

According to KOCH (1985), the recent paragenesis of the walls of the mine workings consists of uranopilite, zippeite and gypsum (see Table 1.). We detected *thenardite* by XRD tests (C83, L81), (HOM 21704); it forms 1–4 cm-sized, white, stalactite-like aggregations. *Gypsum* appears in similar form on the walls of the mine workings, together with aragonite or rarely with calcite. *Jarosite* occurs rarely in yellow, dust-like tarnish. By XRD and EDX, we also detected *zippeite,* but a more detailed investigation would be necessary, considering the substitution possibilities in the zippeite group.

Nagyvisnyó

The secondary sulphates (anglesite, gypsum, jarosite) of this uranium indication, occurring in sandstone, were summarized by VINCZE & SELMECZINÉ (1976–1980).

3.3.3. BAUXITE DEPOSITS

Extremely abundant – iron sulphate-rich – parageneses were formed by epigene and hypergene processes in the Hungarian bauxite deposits (see Table 1.). They were summarized by BÁRDOSSY (1977). We can complete them with *alunogen*, which was found in the dump of the Nagyegyháza deposit, forming white, recent incrustations.

3.3.4. PHOSPHATE INDICATIONS

Jarosite, which occurs together with Al- and Fe-phosphates in the phosphate indications of the Uppony Mountains, was described by ELSHOLTZ, SELMECZINÉ ANTAL & SELMECZI (1969) and SELMECZINÉ (1973).

3.3.5. COAL BEDS

Variegated, mineral-rich sulphate parageneses are known from coal beds (KOCH, 1985). The sulphate minerals appear directly in the coal, on the walls of the mine workings and also on the burning dumps. The largest variety of these minerals was formed on the slowly burning dumps, in the so-called fumarole phase, when they are segregated from vapour. Sulphur and sal ammoniac occur frequently, accompanying the sulphates. In the surroundings of the fumaroles, the loose dump is cemented commonly with „seams" of sulphates (and sulphur and sal ammoniac), with thicknesses up to 1–2 dm. The largest crystals and incrustations are formed on the exhaust holes of the fumaroles. The characteristic sulphate parageneses (except for gypsum and jarosite, which occur everywhere) vary by the mountain ranges.

Tschermigite and aluminite are the characteristic minerals of the Eocene coal beds of the Gerecse Mountains. Epsomite and halotrichite appear here in the mine workings, and the most frequent minerals of the dumps are alunogen, halotrichite and rozenite (see Table 1).

On the dump of the coal beds near Tatabánya, rozenite and melanterite occur frequently.

The coal mine workings and the dumps in the Mecsek Mountains contain alunogen, halotrichite, rozenite and melanterite.

Na-sulphates such as thenardite and sodium alum occur usually in Bátonyterenye (Nógrád coal basin).

Ammonium sulphates appear commonly in the beds of the Borsod coal basin. Species-rich parageneses were found by us here both in the mine workings (Egercsehi) and on the dumps (Ormosbánya, Miskolc-Lyukóbánya, Múcsony, Radostyán). We have no information about any other paragenesis related to coal beds in the Carpathian Basin, that contains as many secondary sulphate species as this one.

Sopron-Brennbergbánya

Gypsum and *jarosite* were detected in small amount from the burned dump of the Hermes shaft. *Rozenite* and *melanterite* were also found on the surface of marcasite aggregates, forming curved fibres or light-green tarnish.

Komló

The sulphate minerals of the coal beds of the Mecsek Mountains were summarized by NOSKE-FAZEKAS & NAGY-MELLES (1969). We can complete the list with the observations of *alunogen* which was found in large amount on the dump of the Komló-Dávidföld mine (XRD C217, C218). Alunogen forms here white, yellowish-white, 1–2 cm thick crusts on the burned aleurolite.

Pécs-Vasas

Various occurrence of *gypsum* was observed in the material of the Vasas open pit. It occurs both in the cracks of the coal and in the enclosing layers, forming a few mm-sized crystals. Yellow, dust-like aggregations of *jarosite* are also common.

Tokod

The sulphate minerals, occurring in the enclosing sedimentary rocks of the coal bed, were summarized by PAPP (1990).

Dorog

Jarosite and *gypsum* appear in a small amount on the old dumps in the Anna Valley.

Esztergom, Lencse Hill

The most commonly occurring sulphates of the dumps of the Lencse Hill mine are *gypsum, jarosite* and *mascagnite*. Jarosite occurs with especially variegated habit, while pyrite and/or marcasite concretions and veinlets appear frequently in the whole coal bed. They can be found both in the coal and in the enclosing rocks, forming dissemination, veins and incrustations. The fossils (shells and snails) that occur in these sedimentary rocks were fully recrystallized into marcasite; therefore, the weathered specimens, consisting of jarosite and goethite are especially remarkable specimens.

Gypsum and mascagnite were found in especially large amounts, together with sulphur on the old, burned dump of the Lencse Hill mine, where they form 1–2 dm thick crusts. *Gypsum* was found in aggregates of a few mm long crystals. *Mascagnite* was detected by

the XRD diffractogram (G391) in greyish-white, botryoidal aggregates, accompanied by sulphur.

Bajna

The following sulphates are known from the brown coal open pit of Hantos-puszta. *Gypsum* aggregates occur in extremely variegated habit, size (the largest ones are 40–50 cm in diameter) and colour (colourless, white, grey, yellow, black) in the enclosing clay and sand layers. *Jarosite* forms dust-like dissemination, 2–3 cm-sized massive aggregates or 1–2 mm thick crusts on the surface of the quite widespread marcasite concretions. *Rozenite* appears commonly in white fibres on the weathered surface of the marcasite-pyrite concretions.

Sárisáp

Gypsum and *jarosite* were detected from the enclosing sedimentary rocks.

Mogyorósbánya

Gypsum and *jarosite* occur frequently in the workings of the brown coal mine. The most interesting mineral here is *tschermigite*, which appears rarely, forming fibrous, 0.5–1 cm thick, white, vitreous veinlets. This appearance is quite similar to an other one, which was found earlier in Tokod. The presence of tschermigite was confirmed by X-ray patterns (C60). Nearly all reflections of the JCPDS card 7-22 appeared on this diffractogram. The largest reflections were detected at the following d values: 100 – 4.32 (4.32), 80 – 4.08 (4.08), 75 – 3.26 (3.27) Å.

Várpalota

The following sulphates were detected from the specimens, obtained from the dump of the Inota-puszta shaft. *Jarosite* and *gypsum* are the most frequent sulphates, they occur in dust-like disseminations or in 1–3 mm-sized aggregates. White, yellowish-white incrustations of *anhydrite* and *mascagnite* appear rarely, as confirmed by X-ray patterns (C53). 36 reflections of mascagnite were found in the diffractogram. In SEM images, the mascagnite-bearing crusts consist of dense intergrowths of fine-lamellar crystals (HOM 19628).

Bicske, Csordakút

The secondary sulphate minerals of the coal bed were described by WEISZBURG (1981).

Tatabánya

Information about the sulphate minerals related to the coal beds of Tatabánya were summarized by KOCH (1985). The formerly burned dumps of the coal mines in the surroundings of the town contain a small amount of sulphates. The widespread ones are *gypsum* and *jarosite*, which occur both in the coal and in the enclosing rocks. Gypsum occurs in smaller amounts than on the other dumps, but jarosite has a quite variable appearance. It forms dust-like disseminations, incrustations, pseudomorphs after pyrite and marcasite and also after fossils, which have been recrystallized into an iron sulphide. White, fibrous aggregates of *rozenite* with a few mm size were found commonly on some dumps, on the surface of the very frequent marcasite-pyrite concretions (XRD C220).

Verőce, Katalin Valley

Jarosite and *gypsum* occurred in a small amount on the dump of the lignite mine (XRD C91) abandoned long ago.

Bátonyterenye

The following sulphate mineral assemblage was detected from the formerly burned dump of the Szoros-patak shaft: *gypsum, jarosite, pickeringite, sodium alum, thenardite.*

Among these, gypsum and jarosite are the most frequent ones; they form few mm-sized, acicular aggregates and yellowish, dust-like segregations, respectively. Thenardite occurs in white, flour-like disseminations. Pickeringite is a characteristic sulphate of the white incrustations.

Sodium alum $NaAl(SO_4)_2 . 12 H_2O$

Sodium alum is known from Hungary only from this deposit. It was detected from white crusts and fibrous aggregates, together with a small amount of gypsum and with quartz grains, which were probably mixed with the sulphates.

18 reflections of sodium alum were detected on the X-ray powder patterns (V96) (Table 8.). The three largest reflections appeared at the following d values: the 100 at 4.24 (4.23); the 50 at 3.66 (3.65); the 40 at 3.96 (3.98) Å. (The corresponding values of the JCPDS card 1-397 are in the brackets). Na, Al and S were detected by EDX.

Gypsum and *jarosite* occur in a small amount on the dump of the Kányás-puszta shaft. Using EDX, we found minerals of the jarosite group that are uncharacteristic for jarosite (they did not contain potassium). In their closest environment, portlandite and a small amount of brucite were found (SZAKÁLL, 1989).

Visonta

Only two sulphate minerals – *gypsum* and *jarosite* – were found in these large lignite open pits, probably because of the small number of collected specimens. Jarosite occurred only in minute amounts, while gypsum usually formed cm-sized, rose-shaped aggregates, but 25–30 cm-sized ones appeared, too. Individual crystals occur rarely, but among them, a remarkable skeletal crystal of 4 cm size was found with perfect edges.

Miskolc-Lyukóbánya

An extremely large variety of sulphate efflorescences have been formed between 1980 and 1990 on the slowly burning dumps of the coal beds. The following data were obtained by instrumental tests (XRD, EDX, SEM and thermal analysis). *Gypsum* occurred with great frequency, forming fibrous or flour-like aggregates. *Hexahydrite* appeared in white, flour-like tarnish or in fibrous aggregations. *Anhydrite* was detected in a small amount, together with gypsum by XRD tests. *Alunogen*, accompanying *millosevichite* and *voltaite*, appeared in white and greyish-white crusts. *Mascagnite* occurred in white, yellowish-white crusts, together – by XRD diffractogram – with a small amount of *koktaite* and gypsum. *Rozenite* was found in white, dust-like aggregates.

Mascagnite, *koktaite* and *millosevichite* were first detected in Hungary from this deposit; therefore, the related investigations will be outlined here. The sulphate paragenesis was accompanied by a large amount of sulphur, less commonly by sal ammoniac, goethite and hematite, rarely by portlandite and albite.

Mascagnite $(NH_4)_2SO_4$ and koktaite $(NH_4)_2Ca(SO_4)_2 \cdot H_2O$

The dirty-white, yellowish-brown, or grey porous crusts of *mascagnite* occurred quite commonly. 1–2 mm-sized spherules of white, lamellar crystals were also found. According to SEM images, these crusts had lamellar or cellular structure (Fig. 21).

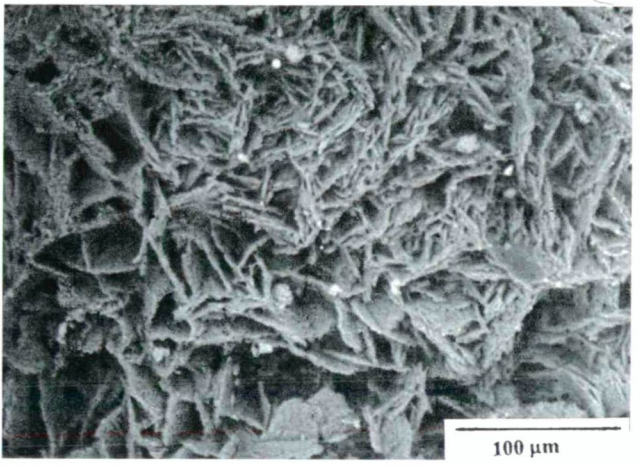

Fig. 21. Mascagnite, porous crusts, Miskolc-Lyukóbánya. Scanning electron micrograph.

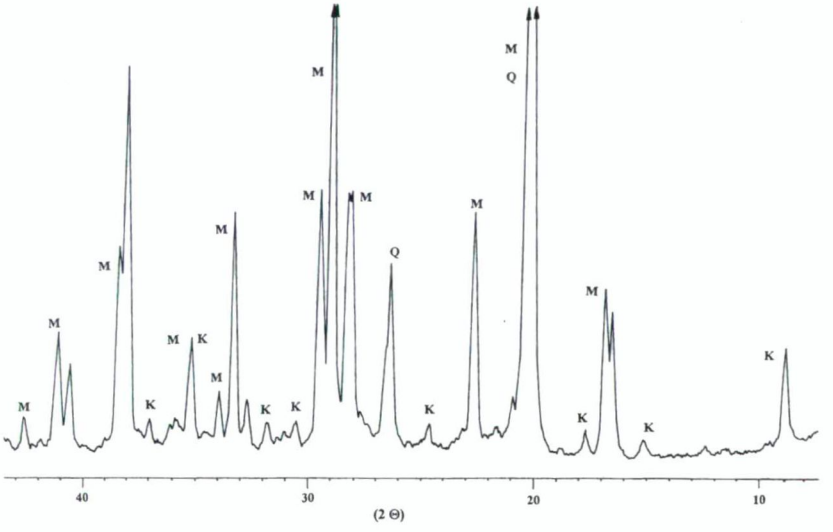

Fig. 22. X-ray powder diffractogram of mascagnite and koktaite, Miskolc-Lyukóbánya. MÁFI, Budapest

56 appreciable reflections appeared on the X-ray patterns (Fig. 22). 19 of these are related to mascagnite. The two largest peaks of quartz and the largest ones of goethite could be identified clearly. 12 reflections of koktaite could be detected; 7 of these –

including the 100 at 10.15 Å (9.83) and the 65 at 3.31 Å (3.30) – are not overlapped (the data of the JCPDS card are listed in the brackets). By the diffractogram, it could be brushite, and/or a small amount of gypsum.

The result of a wet chemical analysis of the specimen, which contains several phases, is the following (compared to the composition of mascagnite and koktaite, according to HÖLZEL, 1992):

	Miskolc-Lyukóbánya	mascagnite	koktaite
SiO_2	11.7		
Fe_2O_3	3.3		
CaO	1.4		19.59
K_2O	1.2		
$(NH_4)_2O$	14	39.41	18.17
H_2O			6.29
SO_3	56.3	60.59	55.94
Σ		100	99.99

Analyst: Mrs. I. SOHA (MÁFI).

Nine endothermic reactions were indicated with weight losses (Fig. 23.) by the thermal analysis of a sample that weighed 100.9 mg and was heated up to 1000 °C. Six reactions of mascagnite were determined by COCCO (1952). Only two reactions were observed on the curve of the thermal analysis of synthetic $(NH_4)_2SO_4$. The data for synthetic $(NH_4)_2SO_4$ were also published by CVETKOV & VALYASHSCIKHINA (1955).

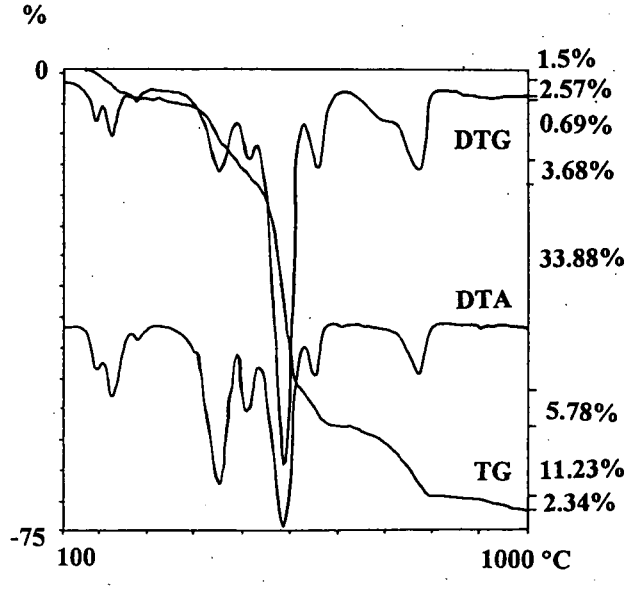

Fig. 23. Thermoanalytical curves of mascagnite and koktaite from Miskolc-Lyukóbánya.

specimen	Cocco (1952) natural	synthetic	Cvetkov & Valyashscikhina(1955) synthetic
92–93 °C			
126 °C			
179 °C	180 °C		
351–354 °C	400 °C	368 °C	350 °C
416 °C	425 °C		410 °C
488 °C	455 °C	502 °C	
556–585 °C	590 °C		555 °C
769–774 °C	790 °C		
948 °C			

The measured weight loss values:

specimen	%	reagent	%
93 °C	1.5		
126 °C	2.57		
179 °C	0.69		
351–354 °C	9.69	368 °C	15.71
416 °C	3.86		
488 °C	33.88	502 °C	77.13
556–558 °C	5.78		
769–774 °C	11.23		
(948 °C)	2.34		

From the above data, the reactions at 352 °C and 556 °C are related to mascagnite. The measured weight losses do not fully agree with the presumed reactions.

1. $(NH_4)_2SO_4 \rightarrow NH_3 + NH_4HSO_4$ – weight loss: 12.9%
2. $NH_4HSO_4 \rightarrow NH_3 + H_2O + SO_3$ – weight loss: 87.1%

The facts, that the measured ignition losses of the specimen are only 72.59% instead of 100%, and that then are further 7 thermal reactions; plus the results of the wet chemical analysis (in accordance with the XRD test), show that the specimen also contains minerals other than mascagnite. If the total CaO-content of the wet chemical analysis were calculated for this mineral, then the specimen would contain probably 7% of koktaite. By XRD diffractogram, the SiO_2-content is associated with quartz, the Fe-content with goethite.

Millosevichite $(Al,Fe)_2(SO_4)_3$

It was detected together with alunogen and/or voltaite using XRD and EDX methods. It forms massive, white, greyish-white crusts (HOM 13886). Three phases could be distinguished on SEM images. *Alunogen* was found in 10–30 μm-sized, tabular crystals (containing Al and S by EDX), *millosevichite* (containing Fe, Al and S) occurred in 15–30 μm long, columnar crystals (Fig. 24.), and *voltaite* was characterized by 10–15 μm-sized, poorly developed crystals (with K-, Fe-, Al- and S-content). 32 reflections of voltaite occurred on the G346 diffractogram, and millosevichite was detected only in a small

amount. The largest three reflections of voltaite were at: the 100 – 3.40 (3.39), the 80 – 3.54 (3.53), and the 60 – 5.56 (5.55) Å d values (the data of the JCPDS card 20-1388 are listed in the brackets).

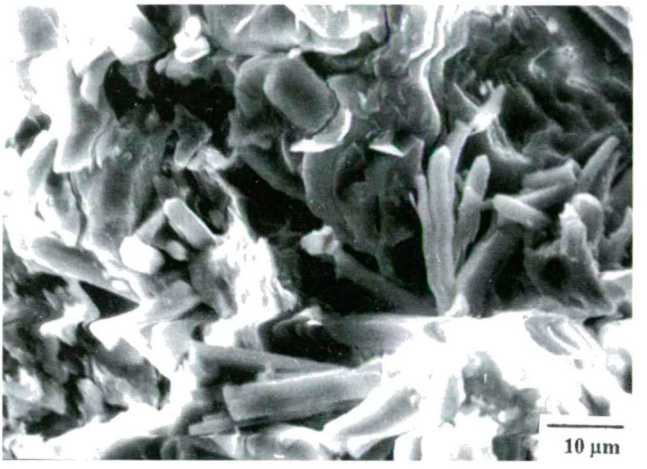

Fig. 24. Millosevichite, columnar crystals with alunogen, Miskolc-Lyukóbánya. Scanning electron micrograph.

One of the dominant phases on the E117 diffractogram is millosevichite, which occurs there together with alunogen. 21 reflections of millosevichite could be detected on the X-ray patterns (Fig. 25.); the largest ones are: the 100 at 3.50 (3.49), the 35 at 2.91 (2.91), and the 30 at 5.81 (5.82) Å d values. A few reflections of an indefinable phase occur together with alunogen on this diffractogram.

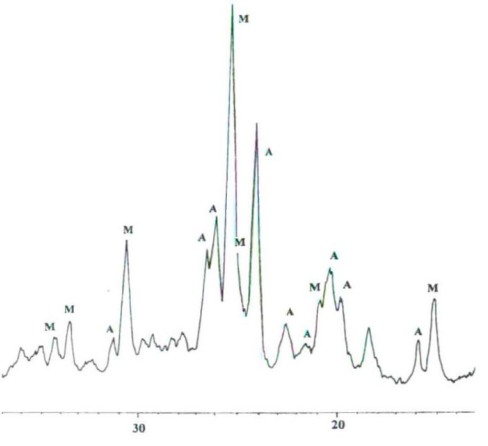

Fig. 25. X-ray powder diffractogram of millosevichite and alunogen, Miskolc-Lyukóbánya. Dept. of Mineralogy, ELTE, Budapest

Ormosbánya

The following minerals were detected from the specimens of the formerly burned dump, near the Ormos shaft, and collected in the period between 1985 and 1990 (XRD E289-296). *Sal ammoniac* appeared most frequently, forming 1–2 cm thick, coarse grained crusts, or flour-like aggregates. Yellowish-white tarnishes of *mascagnite*, *halotrichite*, and *hexahydrite* were found in smaller amounts. *Letovicite* which is only known from here in Hungary, occurred also in minute amounts, together with sal ammoniac and mascagnite. A Ba- and S-bearing phase which appeared in a few μm-sized grains, was detected by EDX; it is probably *barite*.

Letovicite $(NH_4)_3H(SO_4)2$

It was detected together with sal ammoniac and mascagnite in the material which was collected on the dump. It formed white, fine-grained aggregations on the surface of the 1–2 mm long crystals of sal ammoniac, or among the mascagnite aggregates (HOM 17288). In SEM images, letovicite also forms 10–15 μm thick crusts, together with mascagnite on the crystals of the sal ammoniac (Fig. 26.). These crusts are porous and have a rough-fibrous structure on the surface of the fracture. Letovicite was identified by X-ray powder patterns. 9 reflections of letovicite appeared without overlapping on the diffractogram E289 (Table 9.), in addition to the reflections of the much more common sal ammoniac and mascagnite. The thermal analysis indicated that the dominant phase is sal ammoniac, but small endothermic reactions between 600 and 700 °C point to the decomposition of the sulphates mascagnite and letovicite.

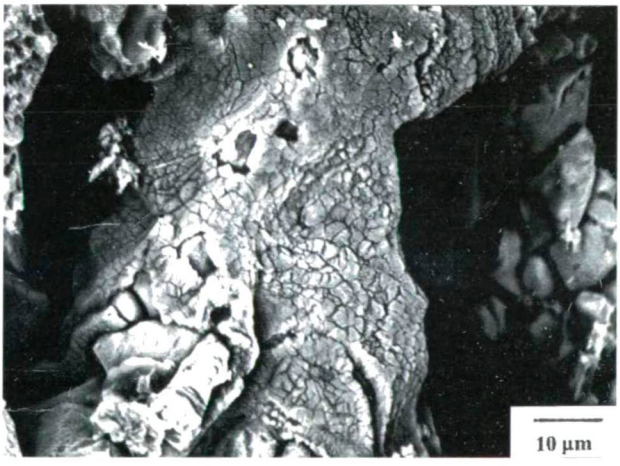

Fig. 26. Letovicite, crusts with sal ammoniac, Ormosbánya. Scanning electron micrograph.

Egercsehi

An interesting sulphate mineral assemblage was collected in the abandoned workings of the mine in the period 1986–1989. The sulphate segregations appeared in a 20–30 m long area on the timbers and in their closest surroundings. The white, yellowish-white crusts and stalactitic aggregates covered an area of a few dm^2 size. By our observations (XRD: E304-307, A226-228, L120, L121), the paragenesis consists of the following minerals: *alunogen* is the main sulphate mineral (forming white, yellowish-white crusts

and tabular crystals) the accompanying minerals are *tamarugite* (in microscopic aggregates, in dense intergrowths with alunogen), *copiapite* (bright-yellow tarnishes and globular aggregates), *halotrichite* (white, acicular aggregates with silky lustre), *melanterite* (light-green crystals of 1–2 mm size and incrustations), and *rozenite* (formed by the decomposition of melanterite and after the disaggregation into a white dust). Here we describe in detail tamarugite, because it was first found in Hungary in Egercsehi.

Tamarugite $NaAl(SO_4)_2 . 6H_2O$

It was usually found in small amounts on the white and yellowish-white incrustations of lamellar crystals of alunogen. The white, 0.2–0.8 mm-sized, thin-tabular alunogen crystals form loose aggregations that look like stacks of cards. In SEM images, the tabular crystals are more often grouped into fan-shaped aggregates (HOM 13075). Tamarugite usually occurs together with these tabular crystals, and only rarely forms self-contained aggregates of a few μm size.

The diffractogram of the crust-like segregations (E307) proved the presence of tamarugite together with the dominant alunogen (Fig. 27.). Nearly 40 reflections of tamarugite appeared on the diffractogram. The peaks with 100 and 60% intensities appear definitely at 4.22 (4.22) and 3.64 (3.65) Å d values. But the 80 peak is uncertain, because it is overlapped by the reflection of the peak with 100 intensity. The result of the wet chemical analysis of the specimen, shows that it consists principally of alunogen; the data are shown below, in comparison with the composition of tamarugite and alunogen, as given by HÖLZEL (1992).

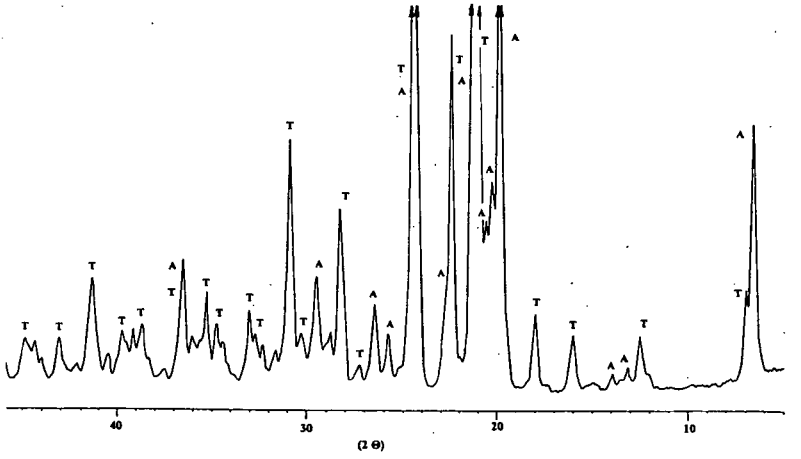

Fig. 27. X-ray powder diffractogram of tamarugite and alunogen, Egercsehi. Dept. of Mineralogy, ELTE, Budapest

	Egercsehi	tamarugite (Hölzel, 1992)	alunogen (Hölzel, 1992)
Al_2O_3	15.56	14.48	14.9
Na_2O	1.03	9.04	
H_2O	42.61	30.9	50.01
SO_3	38.75	45.66	35.09
Σ	97.95	100.12	100

Analyst: Mrs. I. SOHA (MÁFI).

It can be seen from this analysis, that tamarugite appears in this sulphate segregation only in a small amount, accompanied by another mineral (alunogen, according to XRD).

Results of a thermal analysis from a sample that weighed 104.6 mg (Fig. 28.) show:

[°C]	[%]
126	7.65
142	23.69
281	7.34
320	3.93
811	32.56

We did not find any publications about the thermal analysis of tamarugite; however by general experience, the first four reactions could be considered as water losses, and the last one as the decomposition of SO_3. Based on this, the measured water-content was 42.61%, the SO_3 content 32.56%, the ignition losses were 75.65% (up to 1000 °C). Presumably, part of the SO_3-content (about the 1/4) is related to the sodium and will only decompose above 1000 °C. By the water-step proportions, the mineral has 5–5.5 mol water-content (or an integral multiple of that). For comparison, the thermal analysis data of alunogen are listed as follows:

COCCO	DUBANSKY	TODOR	17.5 mol water	theoretical	the specimen with tamarugite	17–18 mol water
°C	°C	°C	%	°C	°C	%
					126	7.65
170	175	140			142	23.69
220			47.9	47.2–48.6	281	42.61
	325	330			320	3.93
910	910	875	35.7	37-36	811	32.56

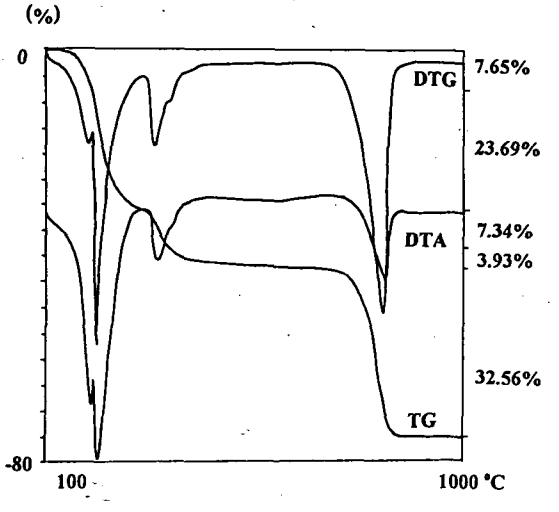

Fig. 28. Thermoanalytical curves of tamarugite and alunogen from Egercsehi.

Szarvaskő

A few sulphate minerals were found on the surface of the burned clay, west from the village, on the dump of the abandoned coal mine of the Keselyű-bérc. *Starkeyite*, *gypsum* and *jarosite* were detected from these segregations. As starkeyite is described for the first time here from Hungary, we introduce the results of the analyses in detail.

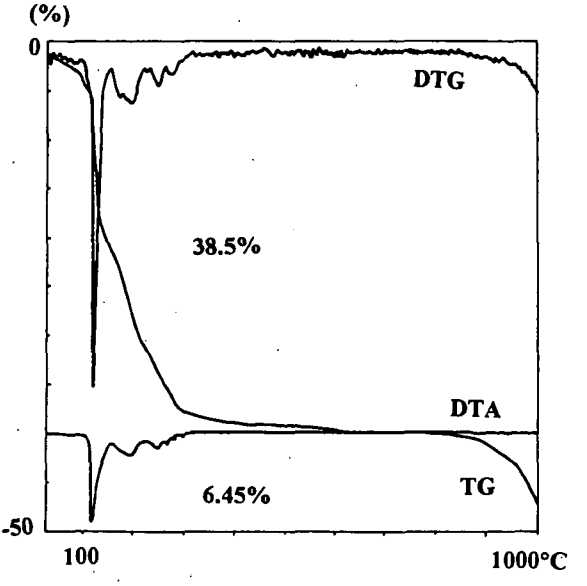

Fig. 29. Thermoanalytical curves of starkeyite from Szarvaskő.

Starkeyite $MgSO_4 . 4H_2O$

It forms snow-white, flour-like tarnish of a few mm thickness in the cracks of the burned sedimentary rocks (HOM 21708). The reactions of the thermal analysis (Fig. 29.) are:

[°C]	[%]
120.8	15.72
192.8	8.62
250.1	2.98
275.7	1.61
>1000	>5.81

The temperatures of the reactions correlate well with the reactions of the water losses (1–4.) and with the decomposition (5.) of the hydrous Mg-sulphate. By the measured water-content, the specimen consists in 77% of starkeyite. 37 reflections of starkeyite were detected on the X-ray powder patterns (L58), in accordance with the data of the JCPDS card. The largest reflections were: the two 100-s at 4.46 (4.48), and 2.94 (2.95), the 60 at 3.96 (3.95) Å d values (the data of the JCPDS card 14-632 are in the brackets). A small amount of quartz and gypsum were detected in the specimen.

Result of the wet chemical analysis:

	specimen	starkeyite (HÖLZEL, 1992)
MgO	17.4	20.95
H_2O	38.5	37.45
SO_3	38.5	41.61
Σ	94.4	100.01

Analyst: Mrs. I. SOHA (MÁFI).

Putnok

The following secondary minerals were detected from the dump of the coal mine: *alunogen, gypsum, goethite, hematite, hexahydrite, jarosite, sulphur* and *sal ammoniac* (XRD E269-275). Alunogen and hexahydrite occurred in white, dust-like efflorescences, while the gypsum formed sub-millimetric acicular aggregates.

Radostyán

White, dirty-white, massive or porous crust-like sulphate aggregates were found in 1995, on the dump of the open pit of the coal bed in Radostyán. These sulphates rarely form white crusts and bundles of dense, fibrous aggregates with silky lustre (HOM 23872). By the instrumental tests, these crusts contain the following sulphates: *alunogen, hexahydrite, gypsum, pickeringite* and *starkeyite*. Sulphur occurs in the closest surrounding of this paragenesis, which is rich in magnesium-sulphates. Pickeringite from Hungary was first found here, therefore we discuss the results in more detail.

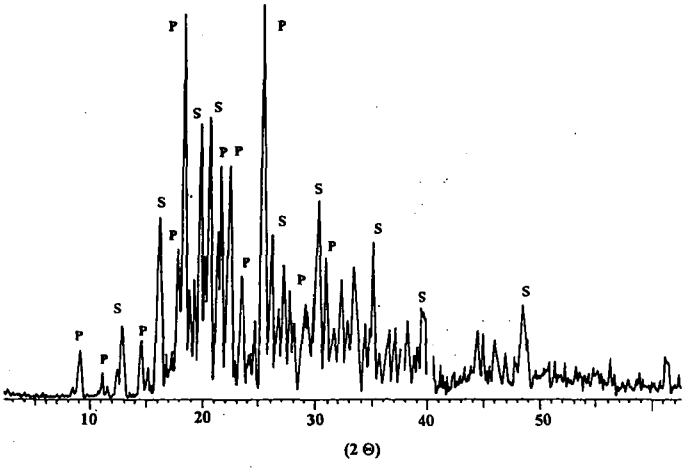

Fig. 30. X-ray powder diffractogram of pickeringite and starkeyite from Radostyán. MÁFI, Budapest

Pickeringite $MgAl_2(SO_4)_4 . 22\ H_2O$

By the X-ray diffraction patterns (G166), the following phases were detected: *pickeringite* (38 reflections), *starkeyite* (59 reflections), and a small amount of gypsum (Fig. 30.). Thermal analysis shows: ignition losses measured up to 1001.3 °C: 66.18%.

The following thermic peaks appeared on the sample that weighed 91.3 mg: 4 reactions with water losses, causing 43.7% total water loss. The sulphate-content related to Al is 15.56%, the sulphate-content related to Mg, up to 1000 °C is 6.71%, the other part decomposes above 1000 °C. Pickeringite is the possible Al-Mg sulphate by the thermal analysis (Fig. 31.), according to the sulphate-content. On the basis of the Al-sulphate steps, it appears that 55% the sample is pickeringite. The remaining water-content is connected primarily with another Mg-sulphate mineral (starkeyite). We cannot find any corresponding mineral phase for the reaction at 520 °C.

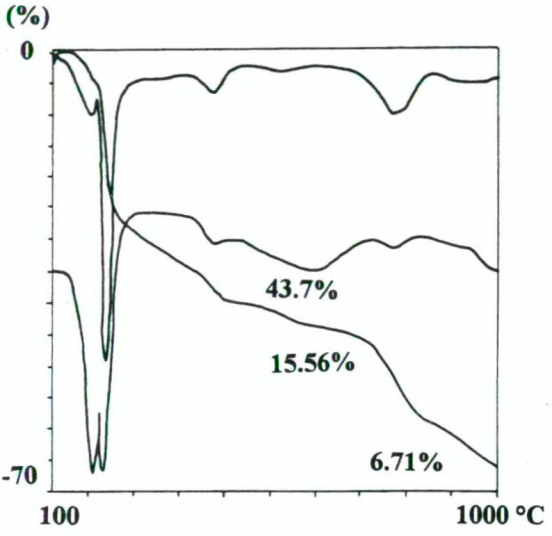

Fig. 31. Thermoanalytical curves of pickeringite and starkeyite from Radostyán.

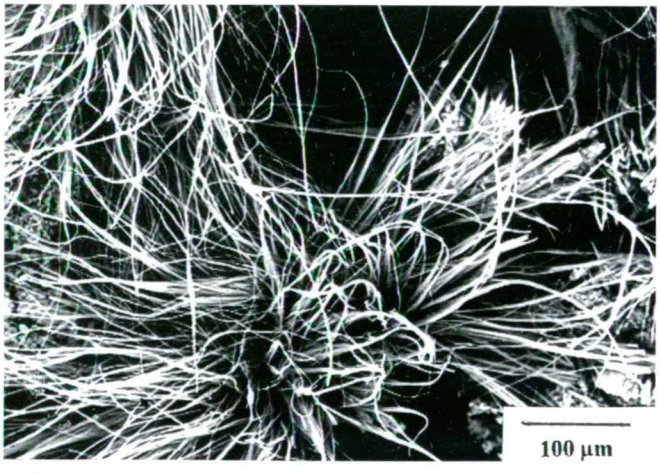

Fig. 32. Pickeringite needles, Radostyán. Scanning electron micrograph.

Hexahydrite occurs on the other two XRD diffractograms together with pickeringite. The sulphate crusts consist of these two minerals, forming white, silky, fibrous aggregates (Fig. 32.). By the result of the thermal analysis – which confirms the XRD diffractogram – the possible Mg-Al sulphate is pickeringite. The proportion of the steps points to the presence of another Mg sulphate mineral (hexahydrite). Mg, Al and S were detected by EDX.

White, flour-like efflorescences of rozenite appeared on the old, burned dump, northwest from the village (XRD E256). They include 2–4 μm-sized grains, which contain Pb by EDX tests. Unfortunately, the reflections of this phase did not appear on the X-ray powder patterns. Presumably it is anglesite(?).

Múcsony

The following minerals were detected from the burning dump of the Szeles shaft: *gypsum*, goethite, *halotrichite*, hematite, sulphur, *mascagnite* and sal ammoniac. *Sal ammoniac* forms white crusts and it occurs in places in deltoidicositetrahedral crystals of 1–2 mm size. Sulphur occurs in the largest amount, forming thick crusts and disseminations. The largest crystals of bipyramidal habit reach 1–3 mm length. Rarely thin tabular crystals and skeletal crystals appeared. Gypsum was found here in 1–2 mm long, columnar crystals, and halotrichite in fine fibres. By XRD tests, mascagnite occurs in dirty-white, crust-like segregations.

Bükkábrány

Only *gypsum* and a mineral from the *jarosite group* were detected in small amounts from this giant open pit. By EDX, K does not occur in jarosite phase, so it needs further investigations.

3.3.5. CLAY-RICH SEDIMENTARY ROCKS (RARELY WITH THE OCCURRENCE OF DISSEMINATED IRON SULPHIDES AND GOETHITE)

Gypsum is a widespread mineral in the clay. Owing to lack of space, the occurrences – which were described by KOCH (1985), and the newer ones, too – are listed in Table 1.

3.3.6. OTHER SEDIMENTARY ROCKS (IN THE ENVIRONMENT OF DISSEMINATED SULPHIDES)

The occurrences of *gypsum* and *jarosite* are well-known in numerous sedimentary rocks (sandstone, chert, limestone). Jarosite, which cements the sandstone in the surroundings of Irota and Gadna is remarkable among these (JÁMBOR, 1960).

The well-known, telethermal marcasite and pyrite of the Pannonian gravel and sand of the Keszthely Mountains occurs in large amounts in some places. An interesting sulphate mineral assemblage appears by their weathering near the surface and on museum specimens.

Rezi

Sulphate efflorescences occur on stored pyrite-marcasite-bearing specimens, which were collected in the Kotyor stream. The XRD, SEM and EDX tests of these specimens

indicate the presence of the following sulphates: *copiapite* – occurring in 1–2 mm-sized yellow aggregates; *rozenite* – in 1–2 mm long, curved fibres; *halotrichite* – forming white masses with silky lustre; *melanterite* – in green spots with glassy lustre; *gypsum* – in white, acicular aggregates, and *jarosite* – forming yellow, dust-like dissemination.

Voltaite $K_2Fe_8Al(SO_4)_{12} \cdot 18H_2O$

It was the first occurrence of voltaite in Hungary, appearing in 0.2–0.4 mm-sized, black crystals with glassy lustre (HOM 23631). The dense intergrown crystals usually form crust-like aggregates. In SEM images, the crystals have a deltoidicositetrahedral shapes (Fig. 33.). K, Fe, Mg and S were detected from these crystals by EDX. 16 reflections of voltaite were identified from the X-ray powder patterns (Table 10.), which agree well with the data of the JCPDS card 17-539.

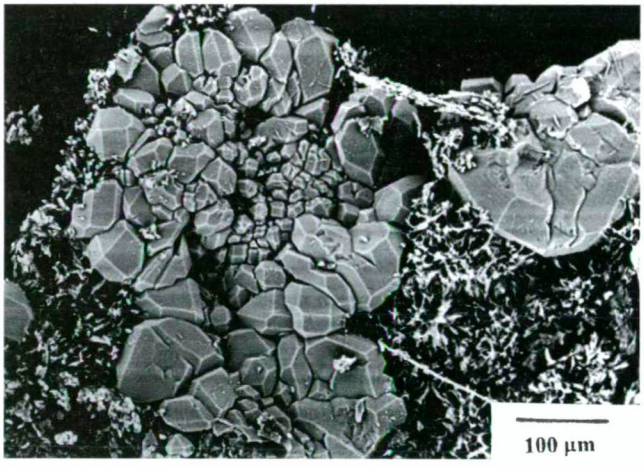

Fig. 33. Voltaite, deltoidicositetrahedral crystals, Rezi. Scanning electron micrograph.

Lesenceistvánd

Zones, cemented with marcasite occurred in different parts of the gravel open pit, situated near the village. The result of the mineralogical investigations of the adjacent secondary sulphates (copiapite, rhomboclase) were published by KOZÁK *et al.* (1985) and by VICZIÁN *et al.* (1986).

The following sulphates were determined by us on specimens that were collected later, on several occasions: *gypsum, halotrichite, jarosite, melanterite* and *voltaite*. (Halotrichite and melanterite were presumed by KOZÁK *et al.* (1985), too, on the basis of IR-spectra). *Jarosite* forms dust-like tarnish, *gypsum* occurs in acicular aggregates, *melanterite* in greenish spots and incrustations, *halotrichite* in white, fibrous aggregates, *rozenite* in white, curved fibres and *voltaite* occurs in crusts of 0.1–0.3 mm-sized black crystals. Considering, that in the different seasons it was possible to collect different parageneses, the formation of sulphates presumably depends on the humidity of the air and on the temperature.

Felsőpetény

Extremely nice gypsum crystals and aggregates, occurring in large variety and size – partially having secondary origin – were found in the large cavities of the limestone and sandstone layers of the clay mine. They were described by KÁKAY SZABÓ (1992). An interesting sulphate paragenesis was recovered in the end of the 1980's and in the beginning of the 1990's, in the end part of the V. mine opening and in several parts of the adit and also in the left side strike of the V/1 cross adit (HOM 21905). The appearance of these sulphates are not surprising, since disseminated pyrite and/or marcasite occur both in the limestone and in the sandstone. The abundance of these sulphides could be observed in several places, commonly occurring in crystals and aggregates of a few mm size. It is sure that the following secondary sulphates have been formed by the weathering of these sulphides which were detected by the instrumental tests (XRD L138, L139). *Starkeyite* occurs in 3–5 cm long, white, fibrous aggregates, *halotrichite* in 1–3 mm-sized, white bundles. *Melanterite* appears in bottle-green nodules of 2–4 cm size, having glassy lustre and in fissures up to 1 cm thickness, appearing in the clay, which is black because of its iron sulphate content. Fibrous, dull, white *rozenite* aggregates were formed by the weathering of melanterite. *Jarosite* appears rarely in light-yellow, earthy patches in the clay. *Gypsum* and a small amount of *jarosite* occur in the large open pit. White, fibrous aggregates of *halotrichite* can be found on the surface of the marcasite-pyrite concretions, which appear in the clay.

Kecskemét, Úri Hill

Together with chlorides and carbonates, several sulphates species occur in the superficial efflorescences of sodaic areas. Among the sulphates, only the appearance of *thenardite* is certain (XRD G240) at present; it forms white, flour-like disseminations.

4. SECONDARY MINERALS, OCCURRING IN METAMORPHIC ROCKS (IN THE SURROUNDINGS OF DISSEMINATED SULPHIDES)

Jarosite was found in numerous outcrops, in the fissures of the metamorphic rocks of the Sopron Mountains. The conditions of the formation of this jarosite are completely the same as the above listed ones; it is mainly connected to the pyrite zones. Jarosite of the gneiss quarry of Kő Hill in Kópháza is remarkable; it occurs in large amounts together with goethite in the outcrops of the gneiss, close to the surface (KISHÁZI & IVANCSICS, 1977). The ocher-brown, yellow jarosite forms 1–3 mm thick incrustations or dust-like aggregations on the walls of the fissures in the gneiss. It appears the goethite as well, forming olive-green, 0.1–0.2 mm thick crusts. In this jarosite, phosphor was also detected by EDX. The ratio of the sulphur and phosphor is 3:1 by semi-quantitative microprobe analysis. As it can be seen on the SEM images, the olive-green crust consists of 15–35 μm-sized thin-tabular crystals. *Gypsum* occurs in the cracks of the goethite residuum, forming 1–2 mm long, acicular crystals. A nearly 2 cm-sized sulphide nodule was found once in the quartz vein of the gneiss. According to the microprobe and ore microscopic investigations, this nodule consists of stibnite, pyrite, chalcopyrite, galena and marcasite. Goethite and *anglesite* were found as secondary minerals on the border of the sulphides.

A small amount of *gypsum* and *jarosite* were found by us in the fissures of the weathered, – secondary iron oxide-rich – serpentinite, which borders the talk deposit of Felsőcsatár. Malachite and azurite also occur in this mineral assemblage.

1–2 mm long *gypsum* crystals appear in large amounts in the old schist quarry of Kisgyőr, Bükk Mountains, on the cleavage surfaces of the clay schist that contains disseminated pyrite. Gypsum, sometimes together with jarosite, occurs frequently in similar structure; in the other clay schist outcrops of the Bükk Mountains. White and colourless incrustations and botryoidal aggregates of *epsomite* and *pickeringite* (XRD, A69) appear together with yellow, dust-like dissemination of *jarosite* on the clay schist walls of the abandoned Heinrich adit, near Dédestapolcsány.

ACKNOWLEDGEMENTS

We wish to thank BÉLA FEHÉR (Miskolc) for his help in data collection. We thank the following researchers for the the instrumental tests: LÁSZLÓ BOGNÁR, MELINDA JÁNOSI, BÉLÁNÉ PETRIK (Budapest), WALTER POSTL (Graz), ISTVÁN SAJÓ, ÉVA SIPŐCZ-MARGITICS (Budapest), GYULA SZÖŐR (Debrecen) and GIOVANNA VEZZALINI (Modena).

We also thank the following collectors for important specimens: JÁNOS CZELE (Balassagyarmat), ANDRÁS FUXREITER (Kecskemét), MIKLÓS GÁL (Komló), GÁBOR GYOMBOLA (Budapest), MÁRTON JUHÁSZ (Tatabánya), SÁNDOR KLAJ (Pécs), LAJOS KÖVECSES-VARGA (Siófok), LÁSZLÓ NÁDAI (Budapest), BÉLA PAPP (Dorog), BÉLA TAVAS (Miskolc), SZABOLCS TÓTH (Recsk) and GYŐZŐ VÁRHEGYI (Budapest).

Numerous interesting specimens were collected in the camps of the Hungarian Friends of Minerals.

We thank FERENC MÁDAI (Miskolc) for the translation.

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TABLE 1.

Secondary sulphate parageneses from Hungary
(mineral species written by italics are the new informations)

I. Sulphide ore deposits

VELENCE MTS.
Szabadbattyán (Kiss, 1951)
anglesite, *fornacite, gypsum, jarosite*
Pátka, Kőrakás Hill, Szűzvár Mill (Kaszanitzky, 1959)
gypsum, *jarosite*
Sukoró, Ördög Hill
gypsum, jarosite

BÖRZSÖNY MTS.
Nagybörzsöny (Nagy: in Koch, 1985)
alunogen, *anglesite,* chalcanthite, *copiapite,* epsomite, gypsum, goslarite, jarosite, melanterite, rozenite, *römerite, siderotil, szomolnokite, voltaite*
Márianosztra, Nagyirtáspuszta (Nagy, 1990)
epsomite, gypsum, melanterite, rozenite

CSERHÁT MTS.
Salgótarján, Karancs Hill
gypsum, jarosite

MÁTRA MTS.
Gyöngyösoroszi, Mátraszentimre (Nagy, 1986)
anglesite, goslarite, gypsum, halotrichite, jarosite, melanterite, rozenite, *thenardite*
Gyöngyösoroszi-Károlytáró
anglesite, gypsum, jarosite
Gyöngyössolymos, Névtelen-bérc adit
devilline, gypsum, jarosite
Parádsasvár, Béke adit
devilline, gypsum, jarosite
Parád-Parádfürdő, Hegyes Hill (Nagy, 1985)
gypsum, halotrichite, jarosite, melanterite
Parád-Parádfürdő, Vaskapu adit (Szakáll & Földvári, 1994)
gypsum, jarosite
Parád-Parádfürdő, Orczy adit
gypsum, jarosite
Parád-Parádfürdő, Hosszú-bérc open pit (Szakáll & Földvári, 1994)
gypsum, jarosite
Parád-Parádfürdő, Egyesség adit
coquimbite, gypsum, halotrichite, jarosite
Recsk, Lahóca Hill (Koch, 1985)
brochantite, chalcanthite, copiapite, coquimbite, gypsum, halotrichite, jarosite, kalinite, mendozite, *szomolnokite*
Recsk, –700 m and –900 m level (Kiss & Jánosi, 1993)
blödite, *bonattite,* brochantite, chalcanthite, epsomite, gypsum, *sideronatrite, siderotil,* thenardite

RUDABÁNYA MTS.
Rudabánya (Koch, 1985; Nagy, 1982; Szakáll, 1992)
anglesite, *antlerite,* barite, *botryogen, brochantite,* chalcanthite, *copiapite, devilline,* epsomite, *fibroferrite,* gypsum, halotrichite, hexahydrite, *jarosite, linarite, magnesiocopiapite,* melanterite, *plumbojarosite, posnjakite, rozenite, serpierite, siderotil, slavíkite, starkeyite, szomolnokite*
Martonyi
gypsum, jarosite, posnjakite

TOKAJ MTS.
Telkibánya (Széky-Fux, 1970; Szakáll et al., 1994)
alunogen, anglesite, gypsum, halotrichite, jarosite, melanterite, plumbojarosite

II. Magmatic rocks

BAKONY MTS.
Badacsonytördemic (Mauritz, 1958)
gypsum

VELENCE MTS.
Velence, Gécsi Hill (Erdélyi & Tolnai, 1954)
jarosite

BÖRZSÖNY
Márianosztra, Medres stream, andesite quarry
gypsum

CSERHÁT MTS.
Karancsberény, Homorú Hill, andesite quarry
gypsum, jarosite

MÁTRA MTS.
Recsk, Csákány-kő Hill, andesite quarry
gypsum
Parádsasvár, Rudolftanya, andesite quarry
gypsum, halotrichite, jarosite
Parádsasvár, Nagylápa-fő, andesite quarry
gypsum, jarosite

BÜKK MTS.
Bükkszentlászló, Messzelátó Hill
jarosite

TOKAJ MTS.
Kéked (Koch, 1985, Szakáll et al., 1994)
jarosite, melanterite, rozenite
Tállya (Tokody, 1965)
epsomite, hexahydrite, gypsum, *jarosite, pickeringite*
Regéc, Torintás (Szakáll, 1992)
gypsum, jarosite
Tolcsva, Tér Hill
jarosite
Komlóska, Bolhás Hill
gypsum

GREAT HUNGARIAN PLAIN
Tarpa (Kulcsár, 1976)
gypsum

III. Sedimentary rocks
III.1. Manganese deposits

BAKONY MTS.
Úrkút (Koch, 1985)
bassanite, gypsum, *jarosite*

III.2. Uranium deposits

MECSEK MTS.
Kővágószőlős (Vincze: in Koch, 1985)
gypsum, *jarosite, thenardite,* uranopilite, zippeite

Sámsonháza (Szakáll, 1992)
gypsum

Kisnána, Hátsó-Tarnóca stream, andesite quarry
gypsum, szomolnokite
Gyöngyössolymos, Kis Hill, rhyolite quarry
jarosite

Abaújszántó, Sulyom Hill, Süveges Hill
jarosite
Gönc, Fenyő-kő Hill, rhyolite quarry
jarosite
Rátka, Hercegköves, limnoquartzite quarry
copiapite, rozenite, szomolnokite
Erdőbénye, Erdőbényefürdő (Földvári, 1942)
gypsum, *jarosite*
Telkibánya, Fehér Hill and Király Hill (Szakáll et al., 1994)
jarosite

Eplény (Koch, 1985)
gypsum, *jarosite*

BAKONY MTS.
Badacsonyörs (Majoros, 1960)
gypsum, zippeite

BÜKK MTS.
Nagyvisnyó (Vincze & Selmeczi, 1976–1980)
anglesite, gypsum, jarosite

III. 3. Bauxite deposits

BAKONY, VÉRTES AND GERECSE MTS.
Eplény, Gánt, Iszkaszentgyörgy, Nagyegyháza, Nyirád, Szőc, etc. (Bárdossy: in Koch, 1985)
aluminite, alunite, *alunogen*, anhydrite, barite, basaluminite, bassanite, celestite, gypsum, *jarosite*, melanterite, parabutlerite, rozenite, szomolnokite

III. 4. Phosphate deposits

UPPONY MTS.
Dédestapolcsány, Nekézseny (Elsholtz, Selmeczíné Antal & Selmeczi, 1969)
gypsum, jarosite

III. 5. Coal deposits

SOPRON MTS.
Sopron-Brennbergbánya, Hermes shaft
gypsum, jarosite, rozenite

MECSEK MTS.
Komló (Noske-Fazekas & Nagy-Melles, 1969)
alunogen, gypsum, halotrichite, jarosite, melanterite, rozenite, szomolnokite
Pécs (Noske-Fazekas & Nagy-Melles,1969)
gypsum, jarosite, melanterite, rozenite, szomolnokite
Hidas (Noske-Fazekas & Nagy-Melles, 1969)
gypsum, jarosite, melanterite, rozenite

BAKONY MTS.
Ajka (Szabó, 1872)
gypsum, *jarosite*
Herend
gypsum
Dudar
gypsum, jarosite
Várpalota, Inota-puszta
anhydrite, gypsum, jarosite, mascagnite, rozenite

GERECSE MTS.
Tatabánya (Koch, 1985)
alunite, epsomite, gypsum, *halotrichite, jarosite, melanterite, rozenite*
Bicske, Csordakút (Weiszburg, 1981)
aluminite, gypsum
Csolnok, Borókás
gypsum
Tokod (Koch, 1985; Papp, 1990)
alunogen, gypsum, epsomite, halotrichite, hydronium jarosite, melanterite, natrojarosite, tschermigite
Mogyorósbánya, open pit
aluminite, gypsum, jarosite, rozenite, tschermigite
Bajna, Hantos-puszta, open pit
aluminite, gypsum, jarosite, rozenite

VÉRTES MTS.
Pusztavám, coal mine
gypsum, jarosite

VISEGRÁD MTS.
Esztergom, Lencse Hill, coal mine
gypsum, jarosite, mascagnite, melanterite, rozenite

BÖRZSÖNY MTS.
Verőce, Katalin Valley
gypsum, jarosite

CSERHÁT MTS.
Kosd (Jugovics, 1915)
gypsum, *jarosite*
Bátonyterenye, Szoros stream shaft (Szakáll, 1992)
gypsum, jarosite, *sodium alum*, thenardite
Bátonyterenye, Kányáspuszta shaft (Szakáll, 1992)
gypsum, jarosite

MÁTRA MTS.
Visonta, lignite open pits
gypsum, jarosite

BÜKK MTS.
Bükkábrány, lignite open pits
gypsum, jarosite
Edelény, Edelény shaft
gypsum, jarosite
Egercsehi
alunogen, copiapite, gypsum, halotrichite, jarosite, rozenite, tamarugite
Ormosbánya, Ormos shaft
barite, gypsum, halotrichite, hexahydrite, letovicite, mascagnite
Izsófalva, open pit
gypsum, jarosite
Királd
gypsum
Kurityán, Fekete Valley shaft
gypsum, hexahydrite, jarosite
Miskolc-Lyukóbánya, Lyukó shaft
alunogen, anhydrite, gypsum, halotrichite, hexahydrite, jarosite, koktaite, mascagnite, millosevichite, rozenite, voltaite
Múcsony, Szeles shaft
gypsum, halotrichite, jarosite, mascagnite
Putnok, Putnok shaft
alunogen, gypsum, hexahydrite, jarosite
Radostyán, open pit
gypsum, hexahydrite, jarosite, pickeringite, starkeyite
Radostyán, old dumps
gypsum, rozenite
Szarvaskő, Keselyű-bérc shaft
gypsum, jarosite, starkeyite

III. 6. Clays (gypsum)
Sopron, Arany Hill, clay mine
Vasvár
Balatonszentgyörgy, clay mine
Szántód, clay mine
Szólád
Nemesvita (Koch, 1985)
Noszlop (Koch, 1871)
Csákvár
Gánt (Toborffy, 1910)
Nagyigmánd (Toborffy, 1907).
Törökbálint
Solymár
Budakalász
Zsámbék
Budapest-Kelenföld (Szontagh, 1882)
Budapest, Bohn clay mine (Brummer, 1937)
Budapest, United Brick Factory, clay mine (Brummer, 1937)
Budapest, Péter Hill (Schafarzik,1913)
Pilisszentkereszt (Schafarzik, 1884)
Lábatlan
Érd (Földvári, 1929)
Páty (Bokor, 1939)
Nógrádmarcal, Magosmáj
Bercel
Kompolt
Szurdokpüspöki (Bárdossy & Hajós, 1963)
Eger, Wind clay mine
Sajóvelezd
Alsótelekes, gypsum open pit (Miklós, 1987)
Alsódobsza (Hoffer,1956)
Szikszó (Fábián & Gimesi, 1937)
Imola (Vitális, 1922)

Szarvas (Szakáll, 1994)
Mezőtúr (Pechácsek-Seres, 1990)
Dévaványa (Pechácsek-Seres, 1990)

Kisújszállás (Szónoky, 1990)
Szeged (Koch, 1985)

III. 7. Other sedimentary rocks

BAKONY MTS.
Rezi, Kotyor stream
gypsum, jarosite, halotrichite, melanterite, rozenite, voltaite

Lesenceistvánd (Kozák et al., 1985; Viczián et al., 1986)
copiapite, gypsum, halotrichite, *jarosite, melanterite,* rhomboclase, *rozenite, voltaite*

BUDA MTS.
Budapest, Mátyás Hill (Koch, 1985)
gypsum
Budapest, Kis-Sváb Hill (Koch, 1985)
gypsum

Budapest, Tündér Hill (Nagy, 1979)
epsomite, gypsum, hexahydrite
Budapest, Gellért Hill (Schmidt, 1900)
gypsum

CSERHÁT MTS.
Vác, Naszály Hill
gypsum
Felsőpetény (Kákay-Szabó, 1992)
gypsum, *halotrichite, jarosite, melanterite, rozenite, starkeyite*

Keszeg (Szakáll, 1992)
gypsum, halotrichite, rozenite
Bátonyterenye (Mauritz, 1958)
gypsum, melanterite

BÜKK MTS.
Miskolc-Diósgyőr, Mexikó Valley, limestone quarry
melanterite, rozenite

CSEREHÁT MTS.
Gadna, Irota (Jámbor, 1960)
jarosite

GREAT HUNGARIAN PLAIN
Kecskemét, Úri Hill
thenardite

IV. Metamorphic rocks

SOPRON MTS.
Kópháza, Kő Hill, quarry (Kisházi & Ivancsics, 1977)
anglesite, gypsum, jarosite
Sopron, Gloriette, quarry
jarosite

Sopron, Vöröshíd
jarosite
Fertőrákos, Gödölye-bérc
jarosite

KŐSZEG MTS.
Felsőcsatár, talc mine
gypsum, jarosite

MECSEK MTS.
Helesfa
gypsum

BÜKK AND UPPONY MTS.
Kisgyőr, quarry
gypsum

Dédestapolcsány, Heinrich adit
epsomite, gypsum, jarosite, pickeringite

TABLE 2.

X-ray powder diffraction data of fornacite from Szabadbattyán

Fornacite, Szabadbattyán		Fornacite, JCPDS 15-200	
d (Å)	I	d (Å)	I
8.23	vw	8.22	50
4.81	s	4.80	90
4.49	vw	4.48	30
4.12	mw	4.12	30
4.03	w	4.00	50
		3.92	30
3.71	m	3.71	50
3.41	vw	3.45	30
		3.38	50
3.32	vs	3.31	100
3.17	mw	3.18	50
3.02	m	3.06	30
2.979	m	2.98	100
2.922	m	2.88	100
2.805	ms	2.80	100
		2.74	30
2.722	ms	2.71	90
2.614	w*	2.62	30
		2.58	30
2.532	w	2.51	30
		2.46	50
		2.43	50
		2.40	50
2.332	m	2.32	30
		2.29	50
		2.24	50
		2.16	30
2.092	mw	2.08	30
2.060	w	2.05	50
2.006	w	2.00	50

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Symbols: vs=very strong, s=strong, m=medium, mw=medium weak, w=weak, vw=very weak, *=broad

TABLE 3.

X-ray powder diffraction data of siderotil from Nagybörzsöny

Siderotil, Nagybörzsöny		Siderotil, JCPDS 22-357	
d (Å)	I	d (Å)	I
		10.5	5
5.72	30	5.73	50
5.56	35	5.57	60
5.06	15	5.07	20
4.88	100	4.89	100
4.56	2	4.57	10
4.35	4	4.35	10
4.04	2	4.04	5
3.89	20	3.90	30
3.69	40	3.73	80
3.43	80	3.44	20
3.27	30	3.29	10
3.20	30	3.21	40
3.08	35	3.07	20
2.93	30	2.92	40
2.86	15	2.86	20
2.77	15	2.76	20
2.71	20	2.72	30
2.66	35	2.68	40
		2.61	5
2.56	20	2.57	10
2.51	30	2.52	5
		2.49	5
2.42	10	2.44	30

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TABLE 4.

X-ray powder diffraction data of antlerite from Rudabánya

Antlerite, Rudabánya		Antlerite, JCPDS 7-407	
d (Å)	I	d (Å)	I
6.81	7	6.8	12
6.02	21	6.01	25
5.42	31	5.40	25
4.86	66	4.86	100
		4.52	10
4.13	7	4.13	8
3.78	14	3.79	16
3.60	52	3.60	75
3.40	24	3.40	10
3.34	34	3.34	10
3.10	21	3.09	16
2.99	14	3.00	18
		2.762	12
		2.698	10
2.688	69	2.683	75
2.570	100	2.566	85

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TABLE 5

X-ray powder diffraction data of linarite from Rudabánya.

Linarite, Rudabánya		Linarite, JCPDS 4-598		Other minerals
d (Å)	I	d (Å)	I	
4.84	7	4.82	20	
4.51	12	4.48	40	
4.25	3			Q
3.62	7			?
3.55	60	3.53	70	S
3.34	15			Q
3.15	25	3.12	100	
3.10	10			?
2.97	6	2.94	20	
2.82	4	2.81	10	
2.75	100			S
2.70	5	2.68	10	
2.58	8			?
2.57	3	2.56	30	
2.45	3			Q
2.39	3	2.39	10	
2.33	25	2.30	30	S
2.26	6	2.24	30	Q
2.18	7			?
2.16	6	2.16	40	
2.11	21	2.09	40	Q,S
2.02	4			?
2.01	6			?
1.949	31			S
1.831	5			?
1.814	6			?
1.795	5	1.79	60b	
1.778	14	1.76	10	S
1.708	38	1.68	20	S

ALUTERV-FKI, Budapest. Symbols: S=smithsonite, Q=quartz.

TABLE 6.

X-ray powder diffraction data of posnjakite from Rudabánya

Posnjakite, Rudabánya		Posnjakite, JCPDS 20-364		Other minerals
d (Å)	I	d (Å)	I	
6.95	35	6.94	100	
6.14	8			?
5.91	8			?
5.42	24			?
		5.25	8	
		5.15	4	
5.00	3	4.85	6	
		4.77	4	
4.26	22			Q
4.18	23			G
3.59	8	3.74	2	
3.52	8			?
3.45	5	3.47	30	
3.34	100	3.33	6	Q
3.13	38	3.23	4	P
3.05	17			?
		2.88	2	
		2.79	2	
2.71	97	2.70	25	P
2.58	5	2.61	16	
2.49	2			G
2.46	26			Q
2.42	44	2.42	25	P
2.39	8			Q
2.34	28	2.33	12	
2.28	15			Q
2.24	3	2.26	8	
2.21	43			P,Q
2.13	5			Q
2.02	46	2.01	12	
1.980	5			Q
1.963	5	1.952	6	
1.913	47			P
1.901	14	1.870	4	
1.814	12			Q
1.757	4			G
1.720	8	1.734	2	
1.690	4			G
1.671	4	1.662	4	
1.633	48	1.616	2	P
1.541	10	1.541	10	

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Symbols: G=goethite, Q=quartz, P=pyrite.

TABLE 7.

X-ray powder diffraction data of serpierite from Rudabánya

Serpierite, Rudabánya		Serpierite, JCPDS 22-0148		Devilline, JCPDS 22-231		Other minerals
d (Å)	I	d (Å)	I	d (Å)	I	
10.19	70	10.20	100	10.22	100	
		5.61	10	5.89	10	
5.09	54	5.09	80	5.08	95	
4.75	19	4.74	40	4.67	40	
		4.37	10	4.40	10	
		3.90	10	3.92	5	
3.69	24	3.53	20	3.73	40	+?
3.39	48	3.39	80	3.38	80	
		3.17	40	3.17	40	
2.94	100	3.01	10	3.01	5	+Ten
		2.83	10	2.87	5	
		2.70	60	2.78	20	
		2.65	60	2.65	60	
2.54	21	2.55	40	2.50	60	+Ten
2.39	18	2.44	60	2.38	40	+Ten
		2.29	20	2.25	40	
		2.23	5	2.21	20	
2.16	16	2.17	60	2.16	5	

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TABLE 8.

X-ray powder diffraction data of sodium alum from Bátonyterenye

Sodium alum, Bátonyterenye		Sodium alum, JCPDS 1-397		Other minerals
d (Å)	I	d (Å)	I	
7.62	18			G
4.24	100	4.23	100	
3.96	31	3.98	40	
3.76	10			G
3.66	47	3.65	50	
3.34	26			Q
3.17	10	3.15	8	
3.07	18			G
3.04	7	3.05	6	
2.91	25	2.90	6	
2.82	4			G
2.78	7			G
2.71	11	2.72	12	
2.60	7	2.60	2	
2.46	13	2.47	8	Q
2.33	5	2.32	6	
2.28	9			Q
2.23	4			Q
2.19	9	2.19	4	
2.12	4			Q
2.08	3			G
2.03	4	2.04	2	
1.908	5	1.90	4	
1.882	4			G
1.819	7			Q,G
1.763	4	1.75	2	
1.703	6	1.69	2	

Dept. of Mineralogy, Eötvös L. University, Budapest.
Symbols: G=goethite, Q=quartz.

TABLE 9.

X-ray powder diffraction data of letovicite, mascagnite and sal ammoniac from Ormosbánya

Letovicite, Ormosbánya		Letovicite, JCPDS 21-25		Other minerals
d (Å)	I	d (Å)	I	
5.50	10	5.47	12	
		4.98	85	
4.94	50	4.95	100	
4.62	15	4.65	35	
4.33				M
3.86				S
		3.81	25	
3.76	100	3.77	80	
3.38	75	3.39	75	
3.35	50	3.36	45	
3.12				M
3.04				M
2.93	30	2.93	50	
2.73				S
		2.71	14	
2.516	15	2.518	25	
2.473	10	2.479	16	
2.317				M
2.231	?	2.232	18	S

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Symbols: S=sal ammoniac, M=mascagnite.

TABLE 10.

X-ray powder diffraction data of voltaite from Rezi

Voltaite, Rezi		Voltaite, JCPDS 17-539	
d (Å)	I	d (Å)	I
9.66	ms	9.66	30
7.79	m	7.92	10
		7.52	10
6.73	m	6.79	30
		6.15	20
5.57	s	5.57	70
4.83	w	4.30	10
4.12	m	4.11	10
		3.91	20
3.75	vw	3.77	20
3.64	w	3.63	20
3.548	vs	3.54	100
		3.46	10
3.41	vs	3.41	90
		3.35	10
3.261	mw	3.21	20
3.159	mw	3.15	30
3.053	m	3.04	50
		2.99	10
		2.93	10
2.867	ms	2.86	30
2.801	vw	2.78	10
2.714	vw		
2.637	mw	2.63	20

Dept. of Geology, University of Modena.

Symbols: vs=very strong, s=strong, m=medium, mw=medium weak, w=weak, vw=very weak, *=broad.